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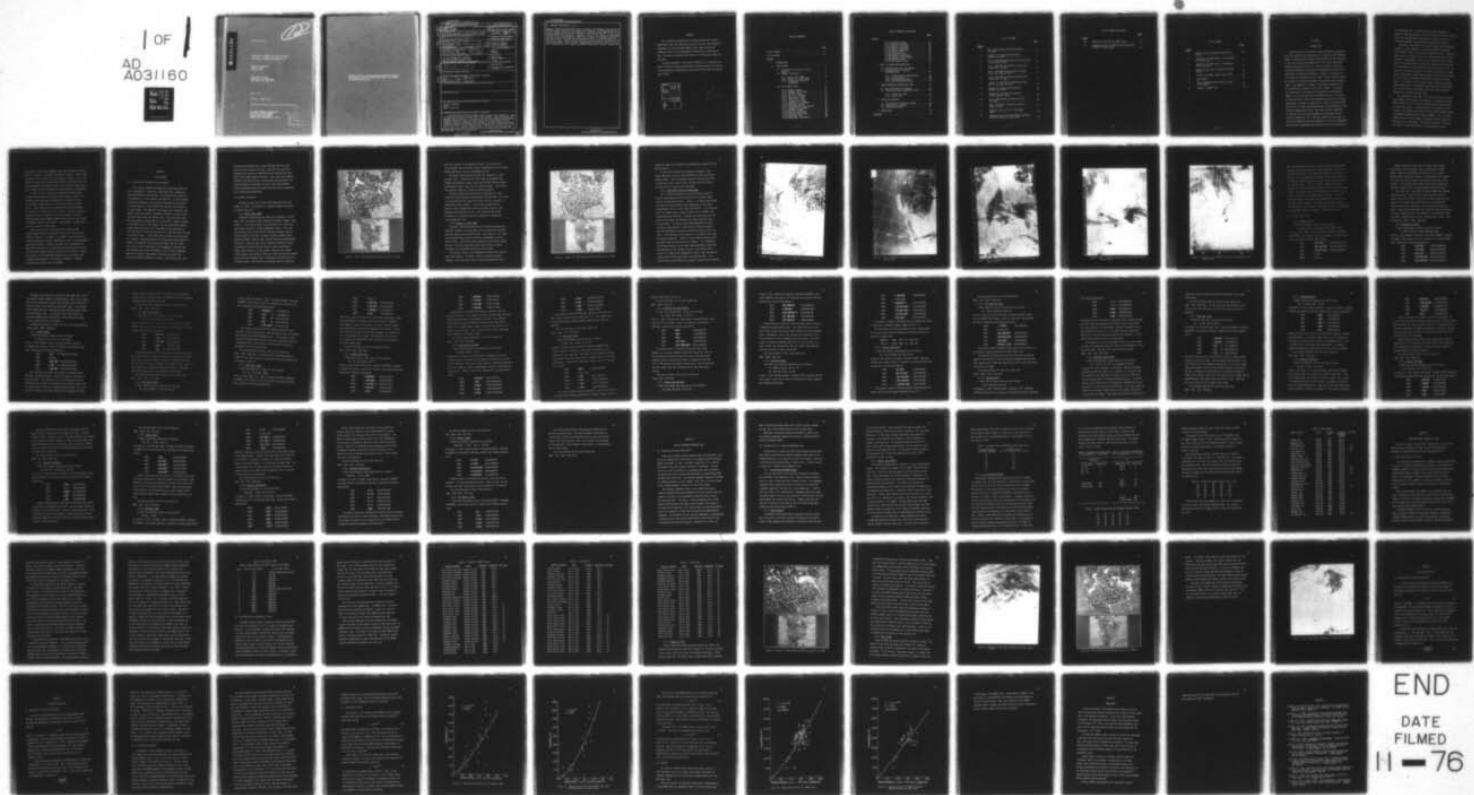
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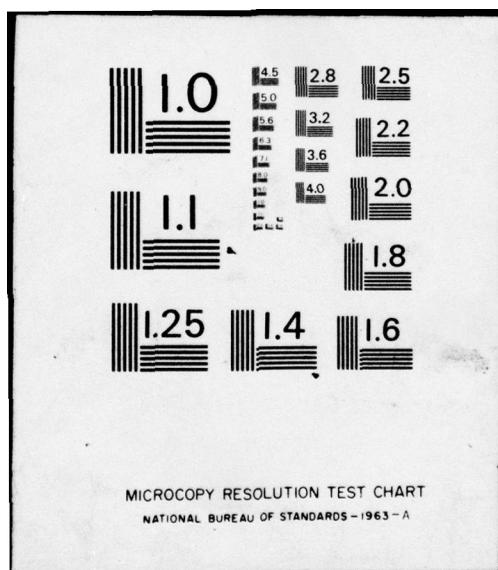
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STATISTICAL INFERENCE OF CLOUD THICKNESS
FROM NOAA IV SCANNING RADIOMETER DATA

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regression curve relating pilot report thicknesses and brightness accounting for 66% ($R^2 = 0.66$) of the variance between the variables, and the regression curve relating 3DNEPH thicknesses and brightness accounting for 46% ($R^2 = 0.46$) of the variance between the variables. Moreover, in view of the effect of cloud compositions on the cloud brightness, regression analyses are performed on both thickness data sources excluding those cases whose origin is an unstable maritime tropical air mass. Results of these regression analyses reveal increases in the correlation between cloud thickness and brightness with 88% and 55% of the variances accounted for pilot reports and 3DNEPH program data sources, respectively.

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PREFACE

This research was supported by the Space and Missiles Systems Organization under the technical direction of the Air Force Geophysics Laboratory, Air Force Systems Command, USAF, under Contract No. F19628-75-C-0107 with the Department of Meteorology, University of Utah. We thank Mr. Bunting of the AFGL for his continuous support on this work.

The work presented in the Scientific Report No. 2 represents one phase of Satellite Sensing and Radiative Transfer research carried out in the Department of Meteorology, University of Utah under the sponsorship of AFGL.

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CHAPTER I

INTRODUCTION

Since the advent of operational weather satellites, meteorologists have sought new and improved ways of exploiting the tremendous amounts of data available through this new medium for the inference of the cloud structure and composition in the earth's atmosphere. Recently, the work of Park et al. (1974) has shown a statistical relationship between the thickness of cumulonimbus clouds and their reflected solar radiance (brightness). However, as discussed by Liou (1975), the approach which was taken in their study to achieve the statistical correlation between cloud thickness and brightness seems "to be hampered by a number of misleading assumptions made in the statistical analysis" (Liou, 1975; pp 645). For example, the clouds used in the study were considered to be blackbodies; however, it is not obvious how a blackbody cloud and a cloud with a lesser emissivity could be distinguished using satellite radiance measurements. Because one cannot easily correct for the different emissivities of clouds, appreciable errors in the evaluation of the cloud top temperatures, used in the study, could be introduced. In addition, the relationship between cloud brightness and the cloud top temperature, one of the basic premises of the study, is not easily understood since the brightness of a cloud is determined by the cloud's composition and thickness, and not by its position

in the atmosphere as is implied by the cloud top temperature. Because of these shortcomings, as well as others discussed by Gruber (1975), an alternate method was taken to arrive at a statistical relationship between cloud thickness and brightness directly.

Physically, the inference of cloud thicknesses from brightness values is a sound hypothesis. Clouds of different thicknesses have different radiative transmission properties, that is, optically thick clouds will transmit less solar radiation than those of less thickness. Consequently, the less solar radiation in the visible part of the spectrum that is transmitted, the more solar radiation will be reflected and the higher the brightness value will be. In addition to the cloud thickness, the physical properties of clouds, such as liquid water content (LWC) and drop size distribution (DSD), will also affect the radiative transmission properties of those clouds. For example, if two clouds of equal thickness had appreciable differences in liquid water content and drop size distributions, the cloud with the greater LWC and the larger DSD would transmit less radiation than the other.

The objective of this study is to show a statistical relationship between cloud thickness and brightness, as observed from the NOAA IV satellite, for low level cloud decks which have no middle or high clouds present. Cloud thicknesses are obtained from two sources; pilot report data and the Air Force Global Weather Central Three-Dimensional Nephanalysis Program (3DNEPH). Thus, two independent sets of data are formed. Brightness values are obtained from the scanning radiometer of the NOAA IV satellite. Owing to the effect of cloud compositions on cloud brightness values,

mentioned in the previous paragraph, the simple concept of air mass origin for clouds is employed in statistical analyses. Since clouds of tropical (or maritime) origin are normally unstable, that is, the particle size and size spectrum change rapidly within the cloud, one would anticipate that clouds of polar (or continental) origin would give a better correlation between the cloud thickness and brightness.

In order to find a statistical relationship between cloud thickness and brightness, the least squares method is used to fit the pilot report data and the 3DNEPH data to regression curves. A coefficient of determination is then found for each of these curves. These coefficients of determination are finally tested for statistical significance using a T-test. Similarly, two other regression curves are found to fit the thicknesses of aircraft reported clouds and the 3DNEPH derived clouds whose air mass origin is different from Maritime Tropical. Coefficients of determination are also derived for these curves.

A description of how pilot reports were chosen and the synoptic weather pattern involved with each pilot report are presented in Chapter 2. In Chapter 3, the NOAA IV satellite and its scanning radiometer package are described, as well as, how brightness values were obtained. Chapter 4 describes the Three-Dimensional Nephanalysis Program, the criteria used for the selection of cases, and the general weather pattern involved with these cases. Finally, a description of the regression analyses used to correlate cloud thickness and brightness, are contained in Chapter 5. General conclusions are cited in the last chapter.

CHAPTER 2

PILOT REPORTS

2.1 Criterion for Selection of Pilot Reports

Pilot reports (PIREPS) were gathered for the days chosen for this investigation. These pilot reports were then screened for their applicability to this study. The following are criteria for the rejection of a pilot report's applicability: a) multi-layered clouds were reported; b) the reported cloud deck was not stratus or strato-cumulus; c) the reported cloud deck was not overcast or at least broken. The remaining pilot reports were compared to the general surface and upper air synoptic conditions, as well as surface observations near the reported area. This was done to check both the accuracy and applicability of the PIREP. Remarks attached to the PIREP, such as "clear above", were not questioned; however, surface observations were still consulted for any observation of cirroform clouds if the PIREP was taken at a time other than the time of the NOAA IV pass. If the pilot report was taken as the aircraft was climbing or descending through the cloud layer during take-off or landing, the reported cloud base and top height may be in error. This error is mainly attributed to the judgement of the pilot and the inherent error of his instruments, since the pilot determines when the aircraft has entered and exited the cloud deck, and since the altimeter tolerance is 75 feet. After talking with five

military and private pilots, it was estimated that this total error could be as much as 150 feet. Once the pilot report was accepted, the location was determined by the latitude and longitude of the closest reporting station. Also, since pilot reports transmit cloud base and tops in height above mean sea level, the station elevation was obtained so that a true cloud thickness could be determined when pilot report data was used in conjunction with surface based observations.

2.2 Synoptic Discussion

The days on which pilot reports were chosen were May 5 and October 11, 1975. The following is a general synoptic discussion for each of the days.

2.2.1 May 5, 1975, 1200Z

The Western United States was under the influence of a closed upper level low pressure center centered in northern Nevada. (see Figure 1) This closed low was also associated with an open long wave trough centered in extreme southwestern Alaska. The trough line extended across southern Alaska southward through Yukon and British Columbia, provinces of Canada, and then southward across eastern Washington, western Idaho, eastern Nevada, and southeastern California. There was weak cold air advection behind the trough associated with the closed low along the coasts of Washington, Oregon, and California. At the surface, there was an occluded front located in the Canadian provinces of Yukon and British Columbia and the extreme northwest corner of Washington associated with the long wave trough. The surface low associated with the closed low

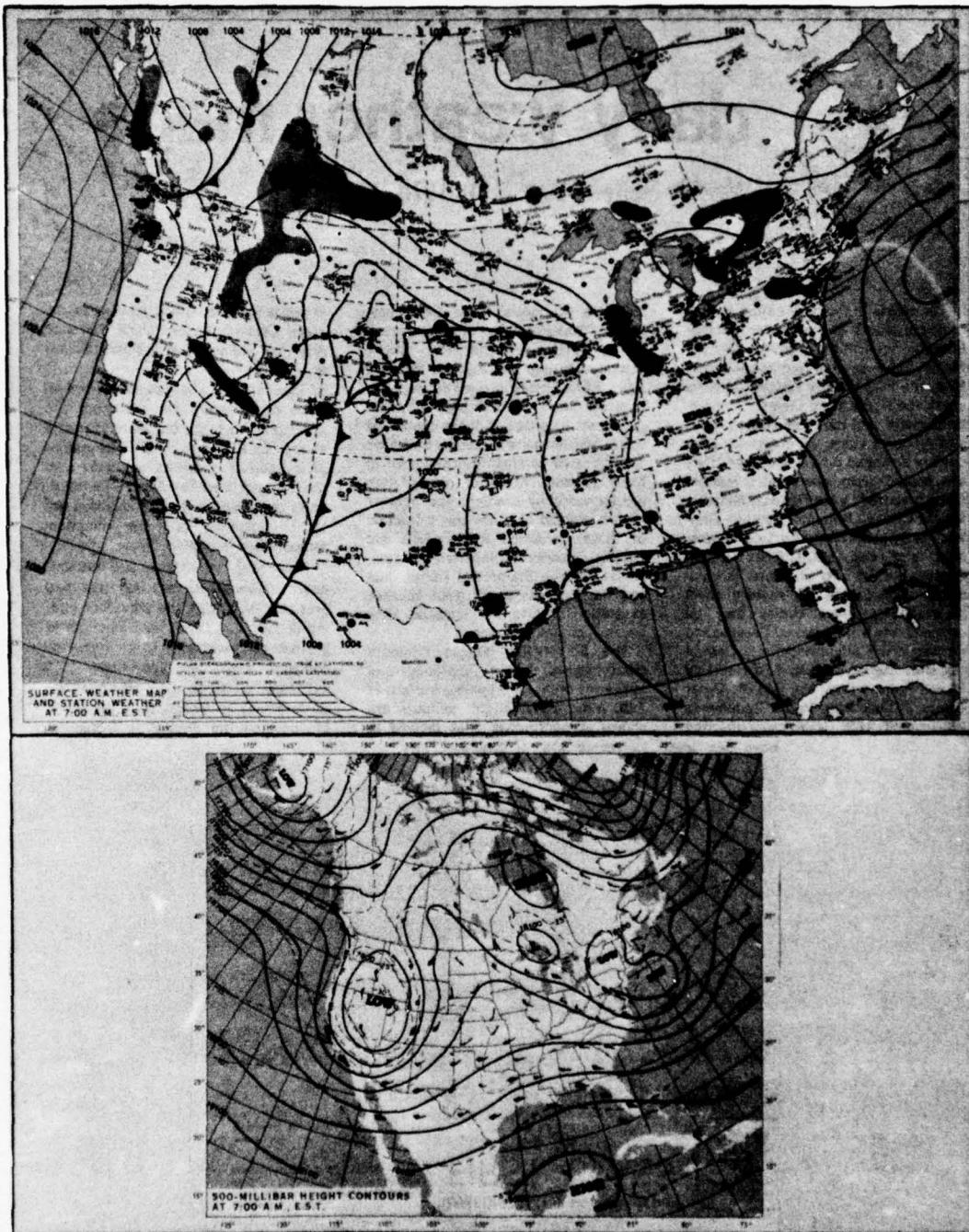


Figure 1. May 5, 1975 Surface and 500 mb Analysis for 1200Z

aloft was centered in northeastern Colorado. The surface cold front extended from the pressure center southwestward across Colorado, western New Mexico, and into northwestern Mexico.

The central United States was under the influence of a high pressure ridge. The 500 millibar (mb) ridge line extended from southern Saskatchewan, Canada, across central North Dakota, eastern South Dakota, western Iowa, and into central Missouri. The surface high pressure center was located in southern Kentucky.

The New England states were under the influence of a weak closed low aloft centered at approximately 37°N and 70°W . The surface low associated with this upper level short wave was centered at approximately 38°N and 65°W . A cold front extended from the pressure center southwestward across the western Atlantic, then westward across northern Florida. From here the front became stationary as it extended across the southern Gulf States and into southeastern Texas.

2.2.2 October 11, 1975, 1200Z

The area of the United States west of the Rocky Mountains was under the influence of low pressure, which at 500 mb was centered along the Oregon and California border. (see Figure 2) The trough axis extended across northern California southwestward into the Pacific Ocean. The surface low was centered in east-central Nevada and had a cold front extending across central Nevada, southern California, and southwestward into the Pacific Ocean.

The central, southern, and southeastern United States were all under high pressure. The 500 mb ridge was oriented northeast-southwest across the plains states, and the southeastern United



Figure 2. October 11, 1975 Surface and 500 mb Analysis for 1200Z

States was under the influence of the Bermuda High centered in the Gulf of Mexico.

A closed low at 500 mb was affecting the weather in the Great Lakes area, as well as the Mid-Atlantic states and the New England states. This low pressure center was located just north of Lake Huron, and it was vertically stacked since the surface low pressure was located at the same point.

2.2.3 Illustrative Satellite Photographs

For illustrative purposes, visual and infrared satellite pictures were obtained from the University of Wisconsin Space Science and Engineering Center. Figure 3 is a Defense Meteorological Satellite Program (DMSP) visual photograph of the western United States for May 5, 1975 from satellite 8531. This satellite pass (orbit 5893) had an equator crossing time of 051920 Z and a descending pass direction. Latitudes are shown along the left side of the picture and longitudes are shown along the bottom of the picture. The picture was gridded geographically and is accurate to approximately $\pm 0.2^{\circ}$ along the satellite subtrack (the vertical dashed line running through the center of the picture). The resolution of this picture is 1/3 nautical mile along the satellite subtrack. Figure 4 is the infrared picture of the same DMSP satellite pass and area of Figure 3. All information and gridding accuracy is the same as described above except that the resolution of the infrared picture is two nautical miles. Figure 5 is a DMSP visual photograph for May 5, 1975 covering the eastern half of the United States from satellite 8531. This satellite pass (orbit 5892) had an equator crossing time of 051735 Z



Figure 3. May 5, 1975 DMSP Visual Satellite Picture with a Pass Time of 1920Z

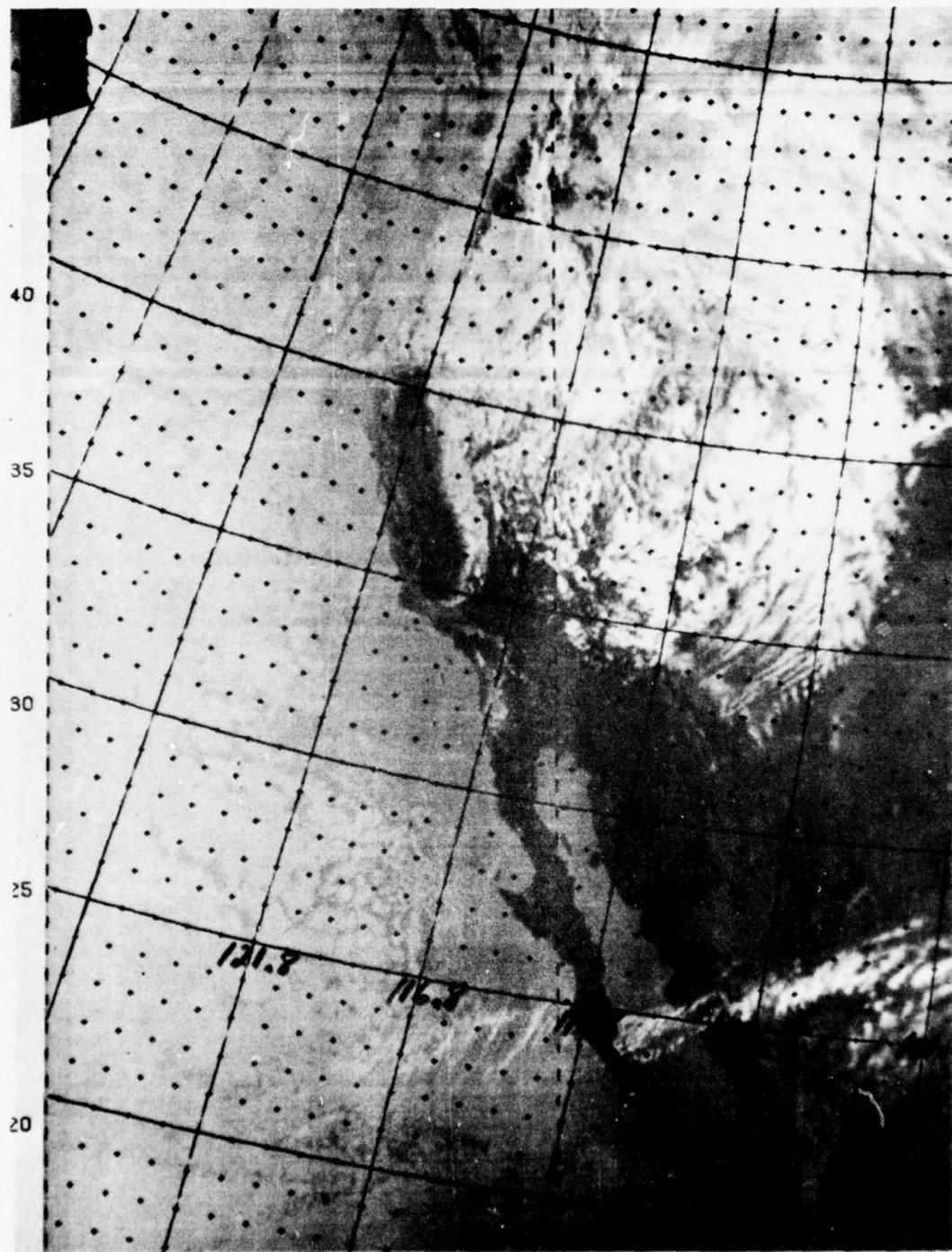


Figure 4. May 5, 1975 DMSP IR Satellite Picture with a Pass Time of 1920Z



Figure 5. May 5, 1975 DMSP Visual Satellite Picture with a Pass Time of 1735Z

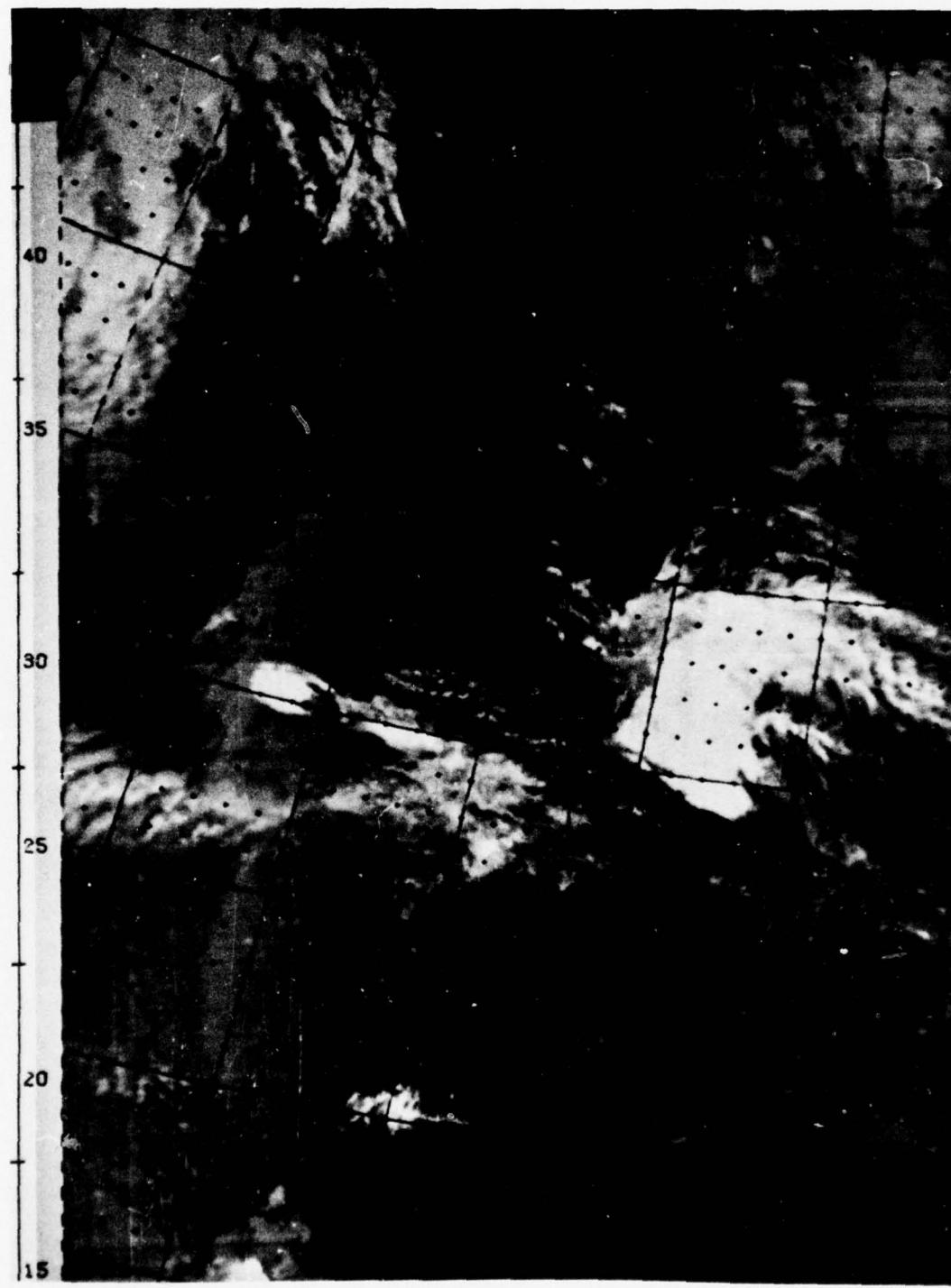


Figure 6. May 5, 1975 DMSP IR Satellite Picture with a Pass Time of 1735Z



Figure 7. October 11, 1975 DMSP IR Satellite Picture with a Pass Time of 1157Z

and a descending pass direction. Other information and gridding accuracy are the same as Figure 3 described above. Figure 6 is the infrared picture of the same DMSP satellite pass and area of Figure 5. All information and gridding accuracy is the same as for Figure 5 except that the resolution of the infrared picture is two nautical miles. Figure 7 is a DMSP infrared picture for October 11, 1975 from satellite 10533 for the north central United States. This satellite pass (orbit 1982) had an equator crossing time of 111157 Z and a descending pass direction. As in the previous figures, this picture was geographically gridded and is accurate to approximately $\pm 0.2^{\circ}$ along the satellite subtrack. The resolution of this picture is two nautical miles. Unfortunately, no other DMSP pictures of October 11, 1975 were available.

2.3 Pilot Report Cases

2.3.1 Eugene, Oregon

A PIREP from Eugene, Oregon was the following:

EUG 051424 DURGC S EUG BASES 50 TOPS 102 CLR ABV

On May 5, 1975, Eugene, Oregon, latitude 44.11667° N, longitude 123.21667° W, (see Figures 3 and 4 for location) and elevation 373 feet, reported the following observations:

1500Z	15①M30⊕10R-	199/46/46/1807/011
1600Z	12①M23①30⊕12	201/47/46/2006/012
1700Z	12①23①M32⊕12	202/50/48/2208/012
1800Z	Missing	
1900Z	Missing	

Eugene, Oregon was to the rear of an upper level trough associated with a closed upper level low centered in northern Nevada. Weak cold air advection to the rear of this trough, coupled with an approaching ridge off the northwest coast, tended to inhibit the vertical growth of the strato-cumulus deck being reported. This observed strato-cumulus deck was associated with the weak occluded front in extreme northwest Washington state.

Since there was a significant difference between the reported and observed bases, since the pilot report was taken south of Eugene during the aircraft's climb, and since the report does not state how far south of the station the aircraft was when the report was made, the reported base of the clouds from the pilot report, rather than the measured bases from the surface observation, was used in determining the cloud thickness. The brightness value for Eugene, Oregon was used for this cloud thickness value. Cloud thickness was $10,200 - 5000 = 5200$ feet.

2.3.2 Montague, California

A PIREP from Montague, California was the following:

SIY 051715 TOPS N SIY APPEAR UNIFORM 90v100

On May 5, 1975, Montague, California, latitude 41.78333° N, longitude 122.46667° W (see Figures 3 and 4 for location), and elevation 2655 feet, reported the following observations:

1500Z	25①E45①20	188/41/35/0000/006
1600Z	25①E40①20	190/44/34/3303/007
1700Z	30①A41①20	189/46/33/2705/007
1800Z	30①E40①75②20	190/46/32/1407/007
1900Z	30①E40①75②20	190/49/31/0000/007

Montague, California was to the rear of the upper level closed low pressure center located in northern Nevada. Weak cold air advection and the approaching ridge off the northwest coast reduced the vertical growth of the observed strato-cumulus deck. This observed strato-cumulus deck was associated with the occluded frontal system on the Washington coast. The gradient flow at the surface was from the northwest which indicated the strato-cumulus was caused by the occluded front to the northwest.

Therefore, the maximum thickness for this pilot report would be 10,000 - 4100 - 2655 = 3245 feet.

2.3.3 Wichita Kansas

A PIREP from Wichita, Kansas was the following:

ICT 051506 12 SE ICT SK 45 WX CLR ABV

On May 5, 1975, Wichita, Kansas, latitude 37.65⁰N, longitude 97.43333⁰W (see Figures 5 and 6 for location), and elevation 1340 feet, reported the following observations:

1300Z	M4 \oplus	2F	045/62/60/1711/969
1400Z	Missing		
1500Z	11	17 \oplus 4F	041/64/60/1814/967
1600Z	M14 \oplus	5F	038/66/60/1912/967
1700Z	16	10 M25 \oplus 7	034/71/62/1813/966

Gulf stratus/strato-cumulus was prevalent throughout Texas, Oklahoma, and southern Kansas. Wichita was under the influence of this cloud deck. The stratus was due to overrunning across the stationary front located in the southern gulf States by warm, moist air from the Gulf of Mexico. Although the 500 mb ridge line was to the east of Wichita, cirroform clouds were not reported at Wichita

but were reported further north. The stratus deck influencing Wichita turned to strato-cumulus by mid-morning and went completely scattered during the afternoon hours.

The cloud thickness obtained from this pilot report was
4500 - 1700 - 1340 = 1460 feet.

2.3.4 Fort Sill, Oklahoma

A PIREP from Fort Sill, Oklahoma was the following:

FSI OVR FSI 051537 OVC 45 CLR ABV

On May 5, 1975, Fort Sill, Oklahoma, latitude 34.65° N, longitude 98.40° W (see Figures 5 and 6 for location), and elevation 1187 feet, reported the following observations:

1300Z	40122 \oplus 3F	62/59/1807/970
1400Z	M25 \oplus 4F	63/59/1808/970
1500Z	10120 \oplus 4F	64/60/1810/969
1600Z	M9 \oplus 3L-F	64/60/1811/968
1700Z	M7 \oplus 3F	65/61/1811/969

With the combination of the stationary front positioned along the southern portion of the Gulf states and a gradient flow in the lower levels which was southerly, stratus was advected from the Gulf of Mexico into Texas, Oklahoma, and southern Kansas. Fort Sill was to the west of the 500 mb ridge line; however, as the pilot report shows there was no cirrus above the stratus deck.

The cloud thickness obtained from this pilot report was
4500 - 2200 - 1187 = 1113 feet.

2.3.5 San Antonio, Texas

A PIREP from San Antonio, Texas was the following:

SAT OVR SAT 051638 15 OVC 60 CLR ABV

On May 5, 1975, San Antonio, Texas, latitude 29.53333°N , longitude 98.46667°W (see Figures 5 and 6 for location), and elevation 794 feet, reported the following observations:

1300Z	M5 10 8 \oplus 1 $\frac{1}{2}$	L-F	71/68/0905/974
1400Z	M6 \oplus	3F	71/68/0904/973
1500Z	M7 \oplus	5FH	73/70/1413/973
1600Z	M8 \oplus	5FH	74/70/1410/972
1700Z	M10 10 15 \oplus 3H		76/71/1412/970

Gulf stratus, resulting from the southerly gradient flow at low levels across the stationary front positioned across the southern Gulf States, was evident throughout Texas. The southerly surface winds at San Antonio during the morning hours assured the station of a continuous flow of warm, moist air from the Gulf of Mexico to perpetuate the life of the stratus.

The cloud thickness obtained for this pilot report was $6000 - 1500 = 4500$ feet. No correction for the station height is needed for this case since the pilot report already has reported the cloud bases in feet MSL.

2.3.6 Idaho Falls, Idaho

A PIREP from Idaho Falls, Idaho was the following:

IDA OVR IDA 051500 \oplus 95

On May 5, 1975, Idaho Falls, Idaho, latitude 43.51667°N , longitude $112.06667^{\circ}\text{W}$ (see Figures 3 and 4 for location), and elevation 4744 feet, reported the following observations:

1400Z	Missing	
1500Z	M12 10 29 ⊕ 20	30/20/2112/974
1600Z	M12 10 29 ⊕ 20	32/21/2113/974
1700Z	M12 10 30 ⊕ 20	M /20/2012/973
1800Z	M24 ⊕ 25	37/21/2010/973

Idaho Falls, Idaho is located in a valley with high mountain ridges running northeast to southwest both to the station's northwest and southeast. Being in the valley, a surface inversion trapped the strato-cumulus deck that was observed at the station. The surface low was to the east of the station; however, the station was still in the upper level trough. This combination of moisture at the surface and instability aloft resulted in the formation of the strato-cumulus deck.

The cloud thickness for this pilot report would be
 9500 - 1200 - 4744 = 3556 feet.

2.3.7 Carswell AFB, Texas

A PIREP from Carswell AFB, Texas was the following:

FWH OVR FWH 052050 OVC 45

On May 5, 1975, Carswell AFB, Texas, latitude 32.78333°N, longitude 97.43333°W (see Figures 5 and 6 for location), and elevation 660 feet, reported the following observations:

1300Z	M35 10 90 ⊕ 10	68/61/1710/974
1400Z	13- 10 M38 ⊕ 8	71/63/1810/974
1500Z	M11 10 24 ⊕ 34 8	74/65/1711/975
1600Z	M11 10 25 ⊕ 8	78/65/1612/972
1700Z	M15 10 8	78/66/1616/971

1800Z	M14 12 8	79/66/1815/967
1900Z	M11 12 8	79/66/1812/967
2000Z	M10 12 8	80/67/1510/965
2100Z	M10 12 8	80/68/1411/962

Surface winds at Carswell AFB indicate a gradient flow from the Gulf of Mexico. This gradient flow was across the weak stationary front positioned across the Southern Gulf States. The southerly flow at the low levels throughout the morning hours assured this station of a constant source of warm, moist Maritime Tropical air to sustain its stratus deck. This stratus deck was evident throughout Texas, Oklahoma, and southern Kansas.

The cloud thickness obtained for this pilot report was
 $4500 - 1100 - 660 = 2740$ feet.

2.3.8 Bartlesville, Oklahoma

A PIREP from Bartlesville, Oklahoma was the following:

8 SW BVO 052140 OVC 52

Bartlesville, Oklahoma, latitude 36.75° N, longitude 96.0° W (see Figures 5 and 6 for location), and elevation 723 feet, has no observations reported. The closest station that was reporting observations was Tulsa, Oklahoma, which is approximately 25 miles to the south of Bartlesville. On May 5, 1975, Tulsa reported the following observations:

1300Z	20 180 10	65/61/1812/975
1400Z	20 10	68/63/1816G20/975
1500Z	M18 10	72/64/2017G22/974
1600Z	M22 12	73/64/1715G24/973
1700Z	M25 12	73/64/1714G21/972

1800Z	M25⊕12	74/65/1715G21/971
1900Z	M21⊕12	75/65/1715G24/968
2000Z	M21⊕10	76/66/1714G22/965
2100Z	M28⊕10	76/66/1715/964

The synoptic pattern affecting this station was basically the same as that affecting Carswell AFB (see 2.3.7). The average base of the clouds between 1500Z and 1600Z (satellite pass time) was 2000 feet.

The cloud thickness for this pilot report was
 $5200 - 2000 - 723 = 2477$ feet.

2.3.9 Manhattan, Kansas

A PIREP from Manhattan, Kansas was the following:

WX DURGC MHK 051940 43 OVC 50

Manhattan, Kansas, latitude 39.15° N, longitude 96.66667° W (see Figures 5 and 6 for location), and elevation 1070 feet, has no observations being reported. The closest station reporting surface observations was Salina, Kansas which is approximately 50 miles west of Manhattan. Observations from Salina, Kansas on May 5, 1975 were the following:

1300Z	A6⊕5H	60/53/1512/964
1400Z	Missing Data	
1500Z	A15⊕7	68/61/1818/963
1600Z	E15⊕7	71/59/1717G25/962
1700Z	E17⊕7	70/55/1718G23/962
1800Z	E25⊕7	72/59/1815G23/960

The synoptic pattern affecting Manhattan, Kansas was basically the same as that affecting Bartlesville, Oklahoma, (see 2.3.8) and

Carswell AFB, Texas (see 2.3.7).

The cloud thickness for this pilot report was
5000 - 4300 = 700 feet.

2.3.10 Ellsworth AFB, South Dakota

A PIREP from Ellsworth AFB, S.D. was the following:

RCA DURGC RCA 051412 37 OVC 53

On May 5, 1975, Ellsworth AFB, South Dakota, latitude 44.15⁰N, longitude 103.1⁰W (see Figures 5 and 6 for location), and elevation 3276 feet, reported the following observations:

1300Z	M6⊕4F	49/48/0306/947
1400Z	M6⊕5F	51/48/0806/947
1500Z	M7⊕6F	53/48/0904/947
1600Z	6⊕M13⊕15	56/50/1104/946
1700Z	13⊕E100⊕250⊕30	62/51/0910/945

Ellsworth AFB was to the west of the upper level ridge; however, no cirrus was reported by the pilot during his climb out. At the surface, Ellsworth AFB was just south of the warm front extending from the low pressure center in northeastern Colorado. This is indicated by the easterly surface winds. One can conclude that the stratus deck over Ellsworth AFB was then warm frontal stratus.

The cloud thickness for this pilot report was
5300 - 3700 = 1600 feet.

2.3.11 Andrews AFB, Maryland

A PIREP from Andrews AFB, Maryland was the following:

ADW DURGC ADW 051005 20 OVC 90

On May 5, 1975, Andrews AFB, Maryland, latitude 38.81667° N, longitude 78.86667° W (see Figure 5 for location), and elevation 279 feet, reported the following observations:

1200Z	9①M13①25④H	52/45/0206/978
1300Z	M10①25④H	53/46/0405/980
1400Z	7①M13①30④4RW-H	53/45/0603/983
1500Z	7①M14①30④5H	54/45/0203/984
1600Z	7①M14①28④5H	55/45/0204/984

Andrews AFB was to the west of the weak upper level closed low influencing the New England states. The station was also to the west of the surface low pressure center located off the New England coast. Northeasterly flow at the surface and northwesterly flow aloft resulted in cold air advection over the station. With this synoptic situation and Andrews AFB being in close proximity to a body of water, the stratocumulus deck over Andrews AFB should not have had any middle or high clouds above.

The cloud thickness of this pilot report was
9000 - 2000 = 7000 feet.

2.3.12 Portland, Oregon

Two PIREPs from Portland, Oregon were the following:

PDX 30NW PDX 051333 OVC 85 - 95

PDX 20SE PDX 051330 OVC 120

On May 5, 1975, Portland, Oregon, latitude 45.6° N, longitude 122.6° W (see Figures 3 and 4 for location), and elevation 39 feet, reported the following observations:

1300Z	E 30 0 60 0 20	46/42/2505/005
1400Z	Missing data	
1500Z	M30 0 55 0 15R-	46/43/1804/009
1600Z	12 0 29 0 M36 0 8R--	47/43/1804/009
1700Z	11 0 26 0 M35 0 7R-	48/45/2207/009
1800Z	18 0 28 0 E35 0 10	53/47/2408/009
1900Z	25 0 E36 0 15	52/44/2710/009

The synoptic situation influencing Portland, Oregon was similar to the pattern influencing Eugene, Oregon (see 2.3.1).

The cloud base at Portland was taken as being representative for the area around Portland; therefore, the cloud thickness for these pilot reports were:

30NW PDX 9000 - 3500 - 39 = 5461 feet

20SE PDX 12000 - 3500 - 39 = 8461 feet.

2.3.13 Seattle, Washington

A PIREP from Seattle, Washington was the following:

SEA OVR SEA 051845 TOPS 100 CLR ABV

On May 5, 1975 Seattle, Washington, latitude 47.45⁰N, longitude 122.3⁰W (see Figures 3 and 4 for location), and elevation 450 feet, reported the following observations:

1500Z	7 0 M15 0 15	45/50/2407/001
1600Z	8 0 M11 0 15 0 15	45/40/2006/004
1700Z	14 0 M18 0 80 0 20	46/40/1706/005
1800Z	14 0 M21 0 40 0 20	47/40/2105/005
1900Z	E21 0 50 0 110 0 20	48/41/1504/005

The synoptic situation affecting Seattle, Washington was the same as that affecting Eugene, Washington (see 2.3.1).

The cloud thickness for this pilot report was
10000 - 450 - 1950 = 7700 feet.

2.3.14 Salt Lake City, Utah

A PIREP from Salt Lake City, Utah was the following:

SLC 12NE SLC 051330 60 OVC 145

On May 5, 1975, Salt Lake City, Utah, latitude 40.76667° N, longitude 111.96667° W (see Figures 3 and 4 for location), and elevation 4227 feet, reported the following observations:

1300Z	-X E15⊕2SW-	33/28/3205/973
1400Z	Missing data	
1500Z	20⊕E40⊕75⊕15	35/26/0110/975
1600Z	20⊕E40⊕100⊕20	39/26/0105/975
1700Z	20⊕E40⊕25	39/26/0108/977
1800Z	20⊕40⊕110⊕25	40/26/3008/977

The synoptic pattern influencing Salt Lake City was similar to the pattern influencing Idaho Falls, Idaho (see 2.3.6).

The reported cloud base from the pilot report was not used to determine the thickness since the cloud base changed from 1500 feet above ground level to 4000 feet above ground level at the time of the satellite pass (1700Z).

The cloud thickness for this pilot report was
14000 - 4000 - 4227 = 6273 feet.

2.3.15 Cleveland, Ohio

A PIREP from Cleveland, Ohio was the following:

CLE 111520 OVR CLE OVC 80

On October 11, 1975, Cleveland, Ohio, latitude 41.4° N, longitude 81.85° W (see Figure 7 for location), and elevation 805 feet, reported

the following observations:

1200Z	CLR 10	43/42/2305/006
1300Z	CLR 10	47/45/2305/007
1400Z	E50 10 10	52/49/2607/008
1500Z	M19 12 12	54/49/2808/008
1600Z	E30 15 15	54/48/2913/009

Cleveland, Ohio was to the west of the upper level trough associated with the closed low centered on the northern shore of Lake Huron. The flow around this low center gave Cleveland a northwesterly surface wind across Lake Erie. It is evident from the observations above that, as the surface winds turned to the northwest, a strato-cumulus deck advected in due to the lake effect.

Since there was an 1100 foot change in the ceiling from 1500Z to 1600Z, an average base height was used for the computation of the thickness value. Therefore, the cloud thickness would be
 $8000 - 2450 - 805 = 4745$ feet.

2.3.16 Watertown, South Dakota

A PIREP from Watertown, South Dakota was the following:

ATY 111520 20 N ATY AT 30 SKIMMING TOP OF FOG

On October 11, 1975, Watertown, South Dakota, latitude 44.91667° N, longitude 97.15° W (see Figure 7 for location), and elevation 1740 feet reported a sky condition of scattered cirrus at 25,000 feet. This was the observation throughout the morning hours. From pilot reports received before the one stated above, Watertown was just to the south of a fairly extensive stratus deck. This stratus deck was caused by a short wave trough moving over the 500 mb ridge whose axis was over the Dakotas. With this short wave strato-cumulus and

stratus was present throughout Montana, North Dakota, and northern South Dakota.

The cloud thickness obtained from this pilot report was $3000 - 1740 = 1260$ feet. It was assumed that the elevation at the point of the pilot report was similar to the station elevation at Watertown.

2.3.17 Kelly AFB, Texas

A PIREP from Kelly AFB, Texas was the following:

SKF 111535 OVR SKF BKN 45

On October 11, 1975, Kelly AFB, Texas, latitude 29.38333° N, longitude 98.58333° W, and elevation 700 feet, reported the following observations:

1300Z	10 133 15	72/72/1701/011
1400Z	15 135 15	75/73/2004/012
1500Z	M17 10 25	77/71/2906/013
1600Z	27 10 25	80/71/2005/014
1700Z	M25 10 25	80/70/2106/012

Kelly AFB, Texas was one of few stations in Texas to report strato-cumulus or stratus ceilings. With the Bermuda High centered in the Gulf of Mexico and the southerly surface winds, it was quite evident that strato-cumulus from the Gulf was being advected into the Kelly AFB area. Although the strato-cumulus was scattered at 1400Z and 1600Z, it was broken at the time of the satellite pass (1500Z) and was reported both at the surface and by the pilot as such. Therefore, this pilot report can be included in this study.

The thickness obtained from this pilot report was $4500 - 1700 - 700 = 2100$ feet.

2.3.18 Hibbing, Minnesota

A PIREP from Hibbing, Minnesota was the following:

HIB OVR HIB 111400 OVC 30

On October 11, 1975, Hibbing, Minnesota, latitude 47.38333°N , longitude 92.85°W , and elevation 1357 feet, reported the following observations:

1300Z	M5⊕4F	43/41/3608/015
1400Z	E7⊕5F	43/41/0000/017
1500Z	E5⊕3L-F	44/42/0000/017
1600Z	E7⊕4L-F	45/42/0708/017
1700Z	E8⊕7	46/42/1205/017

Hibbing, Minnesota was to the east of the 500 mb ridge axis centered over the Dakotas. The surface ridge axis was still to the west of the station so that northerly flow was the predominant flow. With a northerly flow, lake stratus from Lake Superior is evident in eastern Minnesota, and accounts for the stratus deck over Hibbing.

The thickness obtained from this pilot report was
3000 - 600 - 1357 = 1043 feet.

2.3.19 Ontario, California

A PIREP from Ontario, California was the following:

OVR ONT 111810 SKY OVC 78

Ontario, California is at latitude 34.05°N , longitude $117.61667^{\circ}\text{W}$ (see Figures 3 and 4 for location), and elevation 960 feet. There are no observations from Ontario, California; however, this station is located approximately 37 miles east of Los Angeles, California, which has surface observations. Therefore, the surface observations from Los Angeles, California on October 11, 1975 were the following:

1400Z	M7 15 4R-	63/62/1308/994
1500Z	E10 23 60 8	63/62/2011/995
1600Z	M12 25 10	64/60/2210/997
1700Z	12 25 14	66/59/2608/997
1800Z	25 14	66/58/2612/997

Ontario, California is located in a valley approximately 40 miles inland from the Pacific Ocean. Because of this inland location, one can expect the clouds to remain overcast for a longer period of time when compared to Los Angeles observations. Therefore, the base of the overcast layer over Ontario was taken to be the base of the scattered deck over Los Angeles.

Synoptically, Ontario, California has experienced a frontal passage prior to the satellite pass time (1700Z). The station was still experiencing southwesterly flow aloft from the closed low pressure center in northern California.

The cloud thickness for this pilot report was
7800 - 2500 - 960 = 4340 feet.

2.3.20 Seattle, Washington

A PIREP from Seattle, Washington was the following:

SEA OVR SEA 111310 SKY OVC 80

On October 11, 1975, Seattle, Washington, latitude 47.45°N, longitude 122.3°W, and elevation 450 feet, reported the following observations:

1500Z	M4 70 6F	51/49/3607/999
1600Z	M4 7 6F	51/49/0209/999
1700Z	M8 12 7	52/49/0310/000
1800Z	M4 2F	52/49/1105/000
1900Z	M3 2F	51/48/1706/001

Seattle, Washington was to the west of the upper level low pressure center located over north eastern California. Surface features showed a pressure rise due to the high pressure area centered in the Canadian Province of Alberta. Stratus and strato-cumulus was evident throughout the area around Puget Sound, and with a northerly flow both at the surface and aloft moisture advection was sufficient to sustain these cloud bases.

The cloud thickness from this pilot report was
8000 - 450 - 600 = 6950 feet.

2.3.21 Spokane, Washington

A PIREP from Spokane, Washington was the following:

SEA OVR GEG 111538 OVC 32 CLR ABV

On October 11, 1975, Spokane, Washington, latitude 47.63333° N, longitude 117.53333° W, and elevation 2365 feet, reported the following observations:

1300Z	M2⊕3F	44/43/0107/989
1400Z	W2X $\frac{1}{4}$	43/42/3508/989
1500Z	M2⊕1 $\frac{1}{2}$ F	44/42/0310/988
1600Z	M5⊕3F	44/42/0209/988
1700Z	M5⊕8	44/43/0508/988

Spokane, Washington was to the north of the upper level closed low centered in northeastern California. At the surface, Spokane is located in a valley with mountain ranges to the east and west. With a northeasterly flow at the surface, it would seem that a surface inversion capped by the valley location was causing the stratus deck to form in the morning hours.

The cloud thickness for this pilot report was
3200 - 2365 - 500 = 335 feet.

2.3.22 Burley, Idaho

A PIREP from Burley, Idaho was the following:

OVR BYI 111400 OVC 95

On October 11, 1975, Burley, Idaho, latitude 42.53333°N, longitude 113.76667°W, and elevation 4157 feet, reported the following observations:

1300Z	M7⊕10	44/40/2615/980
1400Z	7⊕E12⊕10	40/35/2412/981
1500Z	E7⊕12⊕10R-	41/35/2314/983
1600Z	40⊕E80⊕15	43/36/2111/984
1700Z	30⊕E80⊕150	45/37/2710/984

Burley, Idaho was just to the east of a cold front which, from the station observations, passed the station at approximately 1700Z. Instability caused by the proximity of the cold front caused light rain to fall at the station around 1500Z. After frontal passage middle and high clouds settled over the station, whereas before frontal passage strato-cumulus seemed to be the predominant cloud type.

The cloud thickness for this pilot report was
9500 - 4157 - 950 = 4393 feet.

2.3.23 Lewistown, Idaho

A PIREP from Lewistown, Idaho was the following:

OVR LWS 111945 51

On October 11, 1975, Lewistown, Idaho, latitude 46.38333°N, longitude 117.01667°W, and elevation 960 feet, reported the following observations:

1500Z	W1X $\frac{1}{4}$ F	45/45/0000/986
1600Z	Missing Data	
1700Z	70M10⊕4Gf	46/45/0404/986
1800Z	70M12⊕4Gf	47/44/0000/986
1900Z	100M13⊕10	49/44/0704/986
2000Z	M14⊕10	50/44/2905/986

Lewistown, Idaho was to the west of the upper level trough located in the Western states. Northerly flow was evident both aloft and at the surface. Lewistown is located in a valley with mountain ranges to the east and west. It is also near the Snake River. Due to the proximity of a moisture source and its valley location, a surface inversion was likely to be the dominant force in creation of the stratus deck in the valley.

The cloud thickness for this pilot report was
 5100 - 960 - 100 = 4040 feet.

2.3.24 Bismark, North Dakota

A PIREP from Bismark, N.D. was the following:

DURGD BIS 111406 OVC 35 CLR ABV

On October 11, 1975, Bismark, North Dakota, latitude 46.76667°N, longitude 100.75°W, and elevation 1660 feet, reported the following observations:

1300Z	M4⊕10	40/38/1110/002
1400Z	M7⊕5F	39/38/1008/002
1500Z	M7⊕5F	40/38/1210/000
1600Z	M6⊕5F	42/38/1314/998
1700Z	M7⊕5F	42/38/1112/997
1800Z	M11⊕5F	44/39/1010/995

Bismark, North Dakota was to the west of the surface high pressure ridge axis located in the northern Midwest and south central Canada. The low level flow was from the southeast. Bismark is located near the Missouri River, and, with southeasterly flow, would be influenced by possible stratus from this moisture source. Nearly all of southcentral and southwestern North Dakota had stratus reported during the morning hours because of the stability of the air and the many moisture sources of the Missouri River and its tributaries.

The cloud thickness for this pilot report was
3500 - 1660 - 700 = 1140 feet.

2.3.25 Dickinson, North Dakota

A PIREP from Dickinson, North Dakota was the following:

DURGD DIK 111739 ~~⊕~~37

On October 11, 1975, Dickinson, North Dakota, latitude 46.78333° N, longitude 102.8° W, and elevation 2583 feet, reported the following observations:

1300Z	W2X $\frac{1}{4}$ F	34/32/1313/994
1400Z	W2X $\frac{1}{4}$ L-F	34/32/1314/994
1500Z	W3X 1F	35/32/1313/993
1600Z	W3X 2F	36/33/1311/992
1700Z	W4X 3F	38/35/1012/990
1800Z	E3 ⊕ 6F	40/37/1011/988

The synoptic conditions influencing the stratus deck at Dickinson, North Dakota was similar to that at Bismark, North Dakota (see 2.3.24). Like Bismark, Dickinson is also located near a river (Heart River). Stratus was reported throughout the morning hours.

The cloud thickness for this pilot report was
 3700 - 2583 - 300 = 817 feet.

2.3.26 Medford, Oregon

A PIREP from Medford, Oregon was the following:

DURGC MFR 111500 OVC 37 CLR ABV

On October 11, 1975, Medford, Oregon, latitude 42.36667°N, longitude 122.86667°W, and elevation 1329 feet, reported the following observations:

1400Z	20M7⊕10	48/44/0000/997
1500Z	20M8⊕6F	47/42/1303/998
1600Z	30M10⊕23⊕6F	48/42/1203/000
1700Z	60M9⊕20⊕6F	49/43/0000/001
1800Z	60E9⊕20⊕6F	51/44/3303/001

Medford, Oregon is surrounded on the west, south and east by mountains. In this sheltered area, with a stable air mass over the station, and light surface winds, stratus formed over the station.

The cloud thickness for this pilot report was
 3700 - 1329 - 900 = 1571 feet.

2.3.27 San Antonio, Texas

A PIREP from San Antonio, Texas, latitude 29.53333°N, longitude 98.46667°W, and elevation 794 feet, reported the following observations:

1300Z	8⊕7	73/69/1707/012
1400Z	14⊕10	75/68/2109/013
1500Z	E20⊕12	77/67/1808/014
1600Z	M22⊕15	78/65/2011/015
1700Z	E28⊕15	80/64/1811/014

Gulf stratus was affecting the coastal and inland areas of central and eastern Texas. San Antonio seemed to have moist air from the Gulf of Mexico being advected into its area and with the surface winds from the south, this air was forced to rise because of the mountains to the northwest of the station. A strato-cumulus deck was thus formed.

The cloud thickness for this pilot report was
6000 - 794 - 2000 = 3216 feet.

CHAPTER 3

NOAA IV SCANNING RADIOMETER DATA

3.1 Satellite and Sensor Description

Visual and infrared scanning radiometer data from the NOAA IV satellite was obtained from the National Environmental Satellite Service (NESS) for October 11, 1975. The NOAA IV satellite is in a nominal 732 nautical mile orbit and has a period of 115 minutes. The satellite has a 78⁰ inclination in a retrograde orbit thus providing a sun synchronous nodal crossing with the equator at approximately 0850 and 2050 local solar time. The scanning radiometer package on the NOAA IV satellite contains a visual channel in the .52 to .73 micron range and an infrared channel in the 10.5 to 12.5 micron range.

The scanning radiometer sensor is spin stabilized having a rotating fly-wheel which spins perpendicular to the orbital track and counter to the spin of the radiometer so that the sensor rotates only once per orbit. The sensor is earth oriented by use of pitch sensors, which regulate the speed of the fly-wheel with respect to the speed of the satellite in its orbital path, and attitude controls, which are provided by on board coils providing the needed magnetic torqueing. The resolution of this scanning radiometer is approximately 2 nautical miles in the visible region and 4 nautical miles in the infrared near the satellite subpoint. Because of its orbit, the

NOAA IV satellite provides three sets of data of global coverage per day, two in the infrared and one in the visible range.

Additional information concerning the NOAA IV satellite and its scanning radiometer package can be found in reports by Conlan (1973) and Schwab (1972).

3.2 Characteristics of Scanning Radiometer Data

As described in a report by Conlan (1973) there are three important factors concerning the scanning radiometer which must be considered before any of its data can be used in this study. These are: 1) calibration and normalization of visible data; 2) earth location of data; and 3) mapping and gridding of data.

3.2.1 Calibration and Normalization

Prior to the launch of the satellite, brightness calibration was performed in the laboratory using a source of known brightness such as a quartz iodide bulb and an external filter. The radiometer views the source through the filter and registers "an equivalent brightness compatible with the sun's color temperature." (Conlan, 1973; pp. 47-48) This normalization is dependent upon three angles - the zenith angle of the sun, the scan angle of the satellite, and the angle between the satellite and the sun. However, NESS has used only the correction of the cosine of the solar zenith angle when normalizing the visible data of NOAA IV.

3.2.2 Earth Location

In addition to the normalization correction, one must relate this correction to the data's location with respect to the earth. Several input parameters are necessary to relate the satellite data

to its earth location. These parameters have been thoroughly discussed by Bristor (1970) and are simply listed here. The input parameters are: 1) the orbital elements describing the spacecraft's position; 2) the mounting and alignment of the SR package with respect to the satellite; 3) the angle through which the SR will spin for each earth located sensed target; 4) the location of the horizon for each sweep of the SR; 5) the earth oriented attitude of the spacecraft; and 6) the time relating the SR sweep and the spacecraft's orbital position.

3.2.3 Mapping and Gridding

The scanning radiometer data is mapped in a polar stereographic format. This format can be thought of as a 2048 X 2048 array whose mesh size is four miles near the equator and eight miles near the pole. The actual mapping and gridding accuracy of the data is, of course, directly related to the accuracy of the input parameters of earth location described above. The primary error source for gridding and mapping of the SR data is the spacecraft attitude error. The spacecraft attitude error is related to the roll/yaw error of the spacecraft. Table 1 shows possible earth location errors for a roll/yaw error of 0.1 degrees for six angles of the scanning radiometer from its nadir position. For example, a target image sensed over 1000 nautical miles from the satellite subtrack (50-55 degrees from nadir angle), having a roll/yaw error of 0.1 degree introduced, would have an earth location gridding error of approximately ten nautical miles.

In addition to attitude error, other gridding error sources include the spacecraft altitude error, satellite positioning error, and the internal satellite time error. The total error involved in

mapping and gridding of SR data is normally the sum of the individual error sources; however, based on current use of the satellite product, SR data has a gridding/mapping error of ten nautical miles or less (Conlan, 1973).

Table 1 - Gridding Error Introduced From Attitude Error

SR Angle Deviation From Nadir (degrees)	Gridding Error For 0.1° Roll/Yaw Error (n mi.)
10	1.2
20	1.6
30	2.0
40	3.0
50	7.2
55	13.8

3.2.4 Use of Archived SR Data

The scanning radiometer data obtained from NESS was archived on magnetic tape. The digitized data on the tape was in coded values ranging from 0 to 255 for both the infrared and visible channels. The conversion of the coded values for the visual and infrared channels into units of intensity (brightness) and temperature respectively are shown in Tables 2 and 3 below. A computer program was written to extract the visual and infrared data from the archive tape. This program was written to take the latitude and longitude of the point of interest from the pilot reports and find the corresponding coded brightness and temperature for that point from the archive tape. However, since there could be mapping and gridding errors of up to ten nautical miles inherent to the SR data, it was decided to take an average brightness value around the point of interest to minimize the possible error in the brightness value. To this end,

a 5 X 5 array of brightness points centered around the point of interest was extracted from the archive tape. A double linear interpolation of the brightness values was then performed with each point weighted by its distance from the center point. The weights used were 10%, 20%, and 40%. Table 4 gives the weights for each point in the 5 X 5 array.

Table 2. Conversion of Coded Values to Foot Lamberts in Visible Data

Brightness	
Foot Lamberts	Coded Value
0 - 39	0
40 - 79	1
80 - 119	2
.	.
.	.
.	.
10160-10199	254
Missing data	255

Table 3. Conversion of Coded Values to Temperature (°K) in IR Data

IR	
Temperature (°K)	Coded Value
164.0	0
165.0	1
.	.
.	.
242.0	78
242.5	79
243.0	80
.	.
.	.
.	.
330.0	254
Missing data	255

Table 4. Weight Factors Used for Average Brightness Value

.01	.02	.04	.02	.01
.02	.04	.08	.04	.02
.04	.08	.16	.08	.04
.02	.04	.08	.04	.02
.01	.02	.04	.02	.01

Average brightness values for each of the pilot reports selected in section 3.2 were obtained.

For example, Table 5 below shows the 5 X 5 brightness array for Eugene, Oregon on May 5, 1975. By multiplying each element in the array in Table 5 by its corresponding element in Table 4 (weight factors) and summing the products, the average brightness of 186.06 is obtained.

When relating the scanning radiometer data to its specific pilot report, the factor of time is an important one. The scanning radiometer has a fixed pass time whereas the pilot reports are for many different times. The pilot reports were chosen so that the characteristics of the clouds being reported would not have changed appreciably between the time the PIREP was received and the time of the satellite pass.

Table 5. SR Data for Eugene, Oregon, May 5, 1975

159	156	186	202	174
159	176	190	196	192
181	164	186	216	194
186	162	183	194	194
192	207	190	189	195

Table 6 below lists the summary of all data thus far obtained from pilot reports and scanning radiometer data. Also shown in the table are those pilot reports found in a Maritime Tropical Air Mass (Mt).

Table 6 - Data Summary

PIREP Location	Date	Thickness (ft)	Average Brightness (coded)	Air Mass
Eugene, Ore.	5/5/75	5200	186.06	
Montague, Cal.	5/5/75	3245	146.62	
12SE Wichita, Ks.	5/5/75	1460	143.13	Mt
Fort Sill, Ok.	5/5/75	1113	188.06	Mt
San Antonio, Tx.	5/5/75	4500	155.18	Mt
Idaho Falls, Id.	5/5/75	3556	139.13	
Seattle, Wash.	5/5/75	7700	182.13	
30 NW Portland, Ore.	5/5/75	5461	161.47	
20 SE Portland, Ore.	5/5/75	8461	181.98	
12NE Salt Lake City, Ut.	5/5/75	6273	161.92	
8SW Bartlesville, Ok.	5/5/75	2477	150.76	Mt
Manhattan, Ks.	5/5/75	700	50.29	Mt
Carswell AFB, Tx.	5/5/75	2740	101.82	Mt
Elsworth AFB, S.D.	5/5/75	1600	64.39	
Andrews AFB, Md.	5/5/75	7000	208.67	
Cleveland, Ohio	10/11/75	4745	144.23	
20N Watertown, S.D.	10/11/75	1260	50.47	
Kelly AFB, Tx.	10/11/75	2100	66.97	Mt
Hibbing, Minn.	10/11/75	1043	80.09	
Ontario, Cal.	10/11/75	4340	151.19	
Spokane, Wash.	10/11/75	335	34.67	
Seattle, Wash.	10/11/75	6950	181.52	
Bismark, N.D.	10/11/75	1140	62.66	
Dickinson, N.D.	10/11/75	817	73.56	
Lewistown, Id.	10/11/75	4040	165.24	
Burley, Id.	10/11/75	4393	189.24	
Medford, Ore.	10/11/75	1571	87.97	
San Antonio, Tx.	10/11/75	3216	73.14	Mt

CHAPTER 4

THREE-DIMENSIONAL NEPHANALYSIS DATA

In order to obtain a second set of independently derived cloud thicknesses and brightnesses, data from the Three-Dimensional Nephanalysis program were obtained and are presented here.

4.1 Basic Description of Program

The Three-Dimensional Nephanalysis (3DNEPH) program was developed at the Air Force Global Weather Central (AFGWC) to incorporate the tremendous quantity of satellite sensed cloud data and conventionally sensed meteorological parameters into a three dimensional cloud model of the atmosphere. Maximum efficiency could be achieved through the use of the computer facilities at the AFGWC in handling this vast amount of data to output a high-resolution, operational product.

Basic to the design of the 3DNEPH is the assumption that satellite information is available for its data base in a timely manner. However, in the event that satellite data is not available, the 3DNEPH has the capability of extrapolating past analysis until such time as satellite data does become available.

The 3DNEPH program is built as a series of input processors. These processors include the surface data processor, radiosonde observation (RAOB) processor, aircraft data processor, manual data processor, decision tree processor, satellite video data processor,

satellite infrared data processor, final processor, forecast processor, verification processor, and display processor. Because of the modular nature of the 3DNEPH program, processors can be added to or deleted from the system with a minimum of programming problems. Descriptions and functions of each of the processors can be found in the AFGWC Technical Memorandum 71-2 by Coburn (1971).

The horizontal resolution of the 3DNEPH program is limited by the resolution, and mapping and gridding accuracy of the input satellite data. The hemispheric grid chosen for the 3DNEPH which was compatible with the accuracy of its input satellite data was a 512 X 512 array centered at the north (south) pole of a polar stereographic map and having a distance between grid points of 25 nautical miles at 60⁰ latitude. This 512 x 512 grid was further subdivided into 64 squares (boxes), each containing 4096 grid points to aid in the hemispheric and regional analysis. Once again, each grid point contains information representative of a 25 nautical mile square centered at the grid point when at 60⁰ latitude. The vertical resolution of the 3DNEPH program divides the atmosphere into 15 layers (see Table 6). The first six layers are terrain following layers and the last nine layers are catagorized in feet above mean sea level (MSL).

The possible errors inherent to the 3DNEPH with respect to the scope of this study are threefold. First, cloud thicknesses based on surface observation parameters (i.e. height of the cloud base above mean sea level, cloud amount in the base layer, and present weather) may be in error since the input for thickness is based on averages and not direct observation. The cloud thicknesses based on

infrared satellite data could also be in error since for this study low clouds are exclusively used and the 3DNEPH sometimes interprets low stratus as a clear sky case (Coburn, 1971) because of the relatively small difference in the surface temperature and the cloud radiative temperature. Also, even though the 3DNEPH program makes a correction for atmospheric attenuation in its infrared radiating temperatures, the problem of sensing erroneous cloud top temperatures for layered clouds still remains (Anderson, et al., 1971). Second, cloud amounts in different layers, a parameter used to determine cloud thickness, as determined by the 3DNEPH's use of aircraft reports would be in error. This is because the 3DNEPH catagorizes the aircraft reports into generalized groups (i.e. above clouds (tops less than 10000 feet)) and does not use the actual observed cloud top and/or base measurements of the aircraft reports. Once again, it should be observed that, for the purposes of the 3DNEPH, its method for determining cloud thicknesses from aircraft reports would be adequate; however, for the resolution of cloud thicknesses used in this study the error introduced by the 3DNEPH might result in greater variability in the derived relationship between thickness and brightness. The third source of error for the 3DNEPH results from its basic premise, specifically, that timely satellite data may not always be available for an updata of the program's data base. Therefore, the accuracy of the 3DNEPH is a direct result of the program's updating of the satellite database and accuracy could be improved with increased satellite coverage.

Table 7 (see Coburn, 1971)

Table of Bases and Tops of the 15 Layers of the 3DNEPH

Layer	Base of Layer (feet)	Top of Layer (feet)
1	SFC	150 AGL (Above Ground Level)
2	151	300 AGL
3	301	600 AGL
4	601	1000 AGL
5	1001	2000 AGL
6	2001	3500 AGL
7	3501	5000 MSL (Mean Sea Level)
8	5001	6500 MSL
9	6501	10000 MSL
10	10001	14000 MSL
11	14001	18000 MSL
12	18001	22000 MSL
13	22001	26000 MSL
14	26001	35000 MSL
15	35001	55000 MSL

4.2 Three-Dimensional Nephanalysis Cases

The 3DNEPH program outputs information concerning each 3DNEPH point and also information for all 15 layers of atmosphere above the point. This information includes cloud types, total coverage of cloud, present weather, maximum top, minimum base, and percent coverage for each of the 15 vertical layers. Three-Dimensional Nephanalysis data for Boxes 43, 44, and 52 (corresponding to the United States) on May 4, 1975 and October 10, 1975 were obtained from the United States Air Force Environmental Technical Application Center (USAFETAC) at Ashville, North Carolina. A computer program was then developed to test each of the 3DNEPH points in these Boxes

against certain criteria in order to extract cases applicable to this study. The criteria used were that the total coverage was greater than 75%, that there was no middle or high clouds present, and that the clouds in the low layers were a continuous deck.

After this was accomplished, the output data cases were then screened further to exclude those cases which were over water and whose terrain height was over 6500 feet. Scanning radiometer data was then extracted for each of the cases again using a 5 X 5 array of values around the center point and a double linear interpolation scheme used to determine average brightness. The total number of cases were 87.

The time factor was important when relating the scanning radiometer data to the 3DNEPH data. The 3DNEPH data is processed every three hours beginning at 0000Z on a given day. Care was taken to insure that the time of the 3DNEPH data extracted was as close as possible to the scanning radiometer pass time.

Table 8 below summarizes the cases obtained from the 3DNEPH. Listed in the table are the general location of the point, date, the 3DNEPH derived thickness, and the corresponding scanning radiometer brightness value. Also shown in the table are those 3DNEPH cases found in a Maritime Tropical Air Mass (Mt). The general synoptic situation corresponding to each of the days used for the 3DNEPH cases are described in Sections 4.2.1 and 4.2.2.

Table 8. Summary of 3DNEPH Cases

<u>General Location</u>	<u>Date</u>	<u>Thickness</u>	<u>Brightness</u>	<u>Air Mass</u>
East central Manitoba	October 10, 1975	3700	194.8	
East central Manitoba	October 10, 1975	3600	147.8	
East central Manitoba	October 10, 1975	3900	148.5	
East central Manitoba	October 10, 1975	3900	157.4	
Northwest Ontario	October 10, 1975	3800	169.3	
Northwest Ontario	October 10, 1975	3800	157.5	
Southwest Ontario	October 10, 1975	3300	188.9	
Southeast Ontario	October 10, 1975	3300	178.1	
Northeast Ohio	October 10, 1975	1000	81.1	
Northeast Ohio	October 10, 1975	4900	166.4	
Northwest Pennsylvania	October 10, 1975	4900	168.9	
North West Virginia	October 10, 1975	4500	153.8	
North West Virginia	October 10, 1975	4500	153.3	
West central Texas	October 10, 1975	4300	130.9	Mt
West central Texas	October 10, 1975	4600	161.2	Mt
West central Texas	October 10, 1975	4700	170.5	Mt
West central Texas	October 10, 1975	4500	172.7	Mt
Southwest Texas	October 10, 1975	4500	159.9	Mt
Southwest Texas	October 10, 1975	4600	146.9	Mt
Southwest Texas	October 10, 1975	4550	142.6	Mt
Southwest Texas	October 10, 1975	3600	145.4	Mt
Southwest Texas	October 10, 1975	4700	150.4	Mt
Southwest Texas	October 10, 1975	4500	149.0	Mt
Southwest Texas	October 10, 1975	2700	121.6	Mt
Central Louisiana	October 10, 1975	4200	131.4	Mt
Central Louisiana	October 10, 1975	4300	136.5	Mt
Southwest Texas	October 10, 1975	3300	143.3	Mt
Southwest Manitoba	May 4, 1975	4000	130.0	
Southwest Manitoba	May 4, 1975	3800	118.5	
South Manitoba	May 4, 1975	4200	134.7	
South Manitoba	May 4, 1975	3500	135.1	

Table 8. (continued)

<u>General Location</u>	<u>Date</u>	<u>Thickness</u>	<u>Brightness</u>	<u>Air Mass</u>
South Manitoba	May 4, 1975	4200	130.7	
South Manitoba	May 4, 1975	4300	154.1	
Southwest Manitoba	May 4, 1975	3800	120.8	
Southwest Manitoba	May 4, 1975	3800	125.9	
West central Ontario	May 4, 1975	3900	125.6	
South Manitoba	May 4, 1975	3500	108.1	
Southwest Ontario	May 4, 1975	3600	182.4	
Southwest Ontario	May 4, 1975	3600	167.5	
North Lake Superior	May 4, 1975	4500	172.0	
North Lake Superior	May 4, 1975	4500	199.3	
Southeast Wyoming	May 4, 1975	2000	98.6	
East central Michigan	May 4, 1975	4700	166.1	
East central Michigan	May 4, 1975	4900	168.2	
Southeast Iowa	May 4, 1975	2000	86.2	
Northeast Indiana	May 4, 1975	5200	164.7	
Northeast Indiana	May 4, 1975	5400	146.2	
North Ohio	May 4, 1975	3300	123.3	
North central Texas	May 4, 1975	1000	78.7	Mt
North central Texas	May 4, 1975	1700	83.0	Mt
North central Texas	May 4, 1975	5250	147.0	Mt
North central Texas	May 4, 1975	5200	147.9	Mt
North central Texas	May 4, 1975	5700	177.5	Mt
North central Texas	May 4, 1975	4050	132.6	Mt
Southwest Oklahoma	May 4, 1975	3500	162.0	Mt
Southwest Oklahoma	May 4, 1975	3500	164.9	Mt
North central Texas	May 4, 1975	2800	143.4	Mt
North central Texas	May 4, 1975	5300	169.8	Mt
North central Texas	May 4, 1975	5200	173.1	Mt
North central Texas	May 4, 1975	5200	201.8	Mt
North central Texas	May 4, 1975	5700	191.2	Mt
North central Texas	May 4, 1975	4100	184.3	Mt

Table 8. (continued)

<u>General Location</u>	<u>Date</u>	<u>Thickness</u>	<u>Brightness</u>	<u>Air Mass</u>
North central Texas	May 4, 1975	4000	126.0	Mt
Northeast Texas	May 4, 1975	3500	121.6	Mt
Southwest Arkansas	May 4, 1975	4200	130.0	Mt
Southwest Arkansas	May 4, 1975	4400	160.5	Mt
Southwest Arkansas	May 4, 1975	4400	131.8	Mt
North central Texas	May 4, 1975	2800	145.7	Mt
North central Texas	May 4, 1975	2900	170.2	Mt
North central Texas	May 4, 1975	5700	203.3	Mt
Northeast Texas	May 4, 1975	3500	120.7	Mt
Northeast Texas	May 4, 1975	4000	142.7	Mt
Central Texas	May 4, 1975	1000	119.8	Mt
East central Texas	May 4, 1975	4000	157.3	Mt
East central Texas	May 4, 1975	3500	165.9	Mt
East central Texas	May 4, 1975	4100	181.0	Mt
East central Texas	May 4, 1975	4200	177.1	Mt
East central Texas	May 4, 1975	4200	128.7	Mt
East central Texas	May 4, 1975	4200	154.5	Mt
East central Texas	May 4, 1975	4300	153.0	Mt
East central Texas	May 4, 1975	4300	161.6	Mt
Central Texas	May 4, 1975	1000	115.7	Mt
East central Texas	May 4, 1975	2900	121.4	Mt
Southeast Texas	May 4, 1975	3500	162.4	Mt
Southeast Texas	May 4, 1975	3500	159.6	Mt
South Louisiana	May 4, 1975	4400	147.0	Mt
South Louisiana	May 4, 1975	4000	164.0	Mt

4.2.1 October 10, 1975

Figure 8 shows the surface and 500 mb analysis at 1200Z. The western United States was under the influence of a closed low pressure center located just off the coast of Washington and Oregon. At the surface, there was a stationary front in western Washington extending

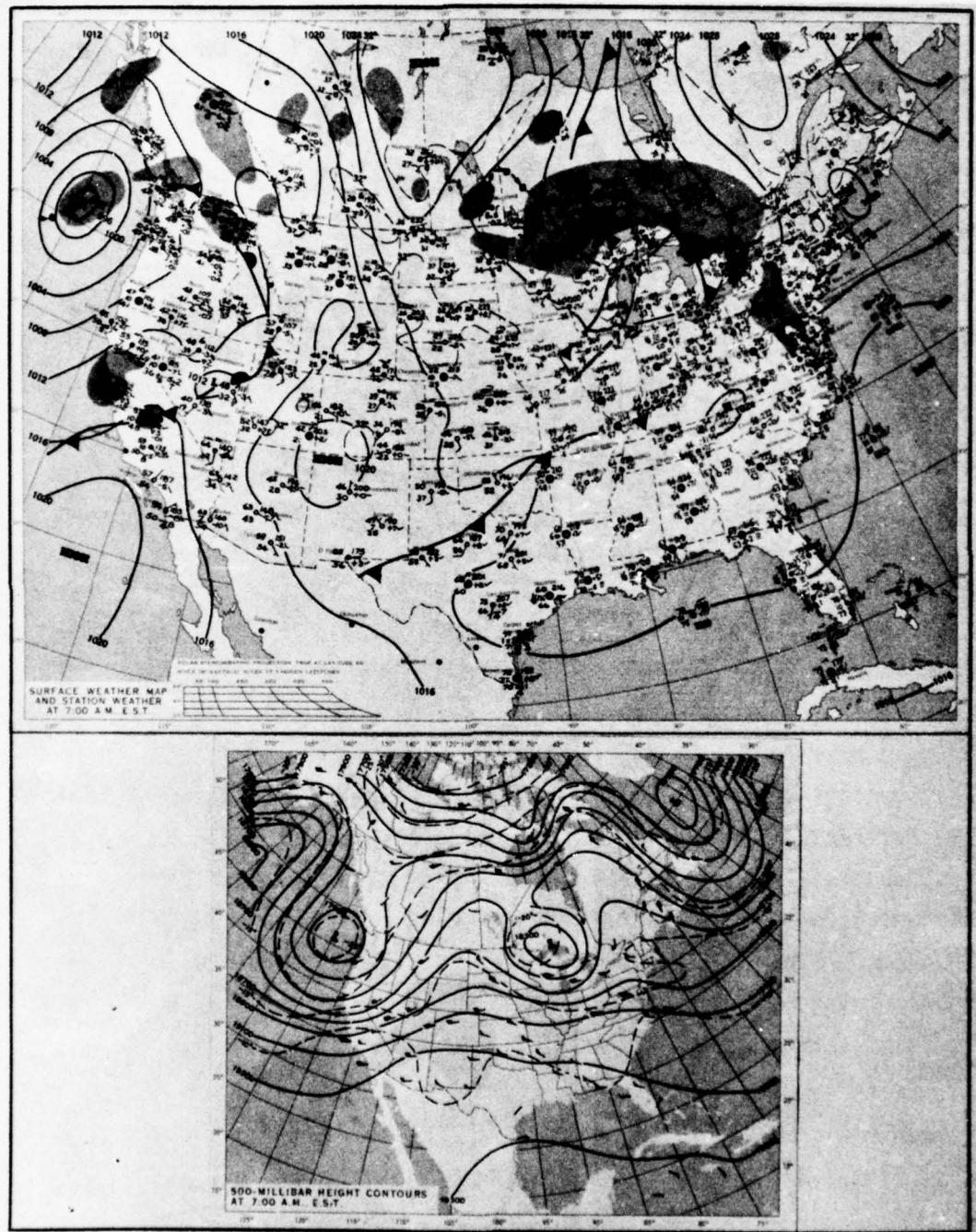


Figure 8. October 10, 1975 Surface and 500 mb Analysis for 1200Z

southwesterly through central Idaho and northwestern Utah. There was a low pressure center in central Nevada with a cold front extending southwesterly across Nevada, central California, and into the Pacific Ocean. A high pressure area was dominating the Rocky Mountain states and the western Midwest as well as the central provinces of Canada. The Great Lakes region was under the influence of a weak closed low pressure center at 500 mb. The surface low was located in northern Lake Superior. This surface low had an occluded front extending southeastward to northern Lake Huron. From here a cold front extended southward across central Ohio and then southwesterly across northern Kentucky, southern Missouri, central Oklahoma, and northern Texas. The Gulf Coast states had very weak winds aloft and reduced visibilities due to fog at the surface.

Since there were no DMSP satellite photographs available for October 10, 1975, a satellite photograph was obtained from the National Weather Service to illustrate the synoptic conditions for that day (see Figure 9). This photograph was taken from the Stationary Meteorological Satellite, SMS-2. At an altitude of 35,700 km, this satellite is stationary over 135°W longitude. Figure 9 is an infrared picture of the western half of the United States taken at 101615Z with a resolution of one nautical mile.

4.2.2 May 4, 1975

Figure 10 shows the surface and 500 mb analysis at 1200Z. The western United States was under the influence of a closed low pressure center at 500 mb, centered over the states of Washington and Oregon. At the surface, low pressure centers in northern Utah and northwest Wyoming brought precipitation to Montana, Idaho, and

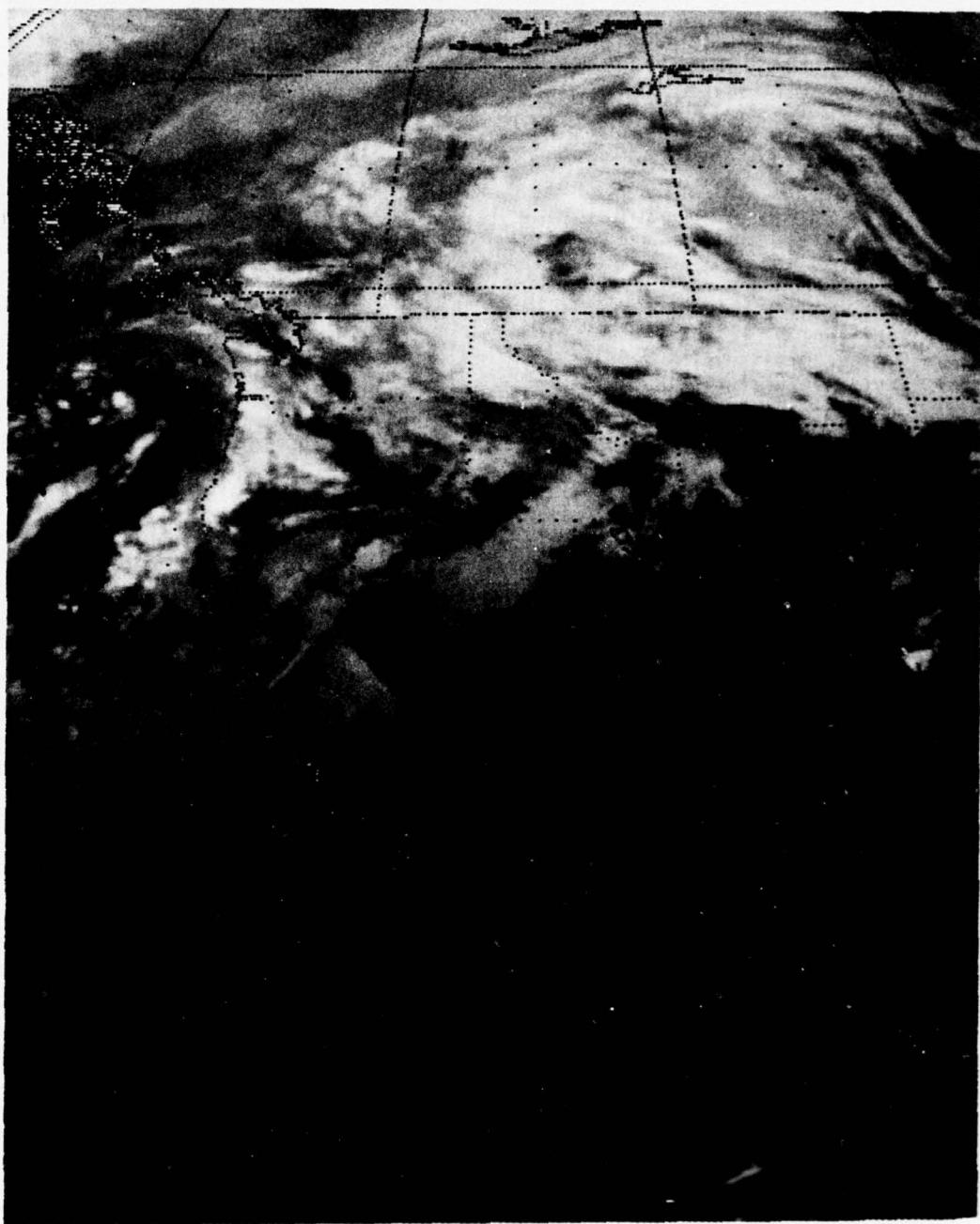


Figure 9. October 10, 1975 SMS-2 IR Satellite Picture taken at 1615Z

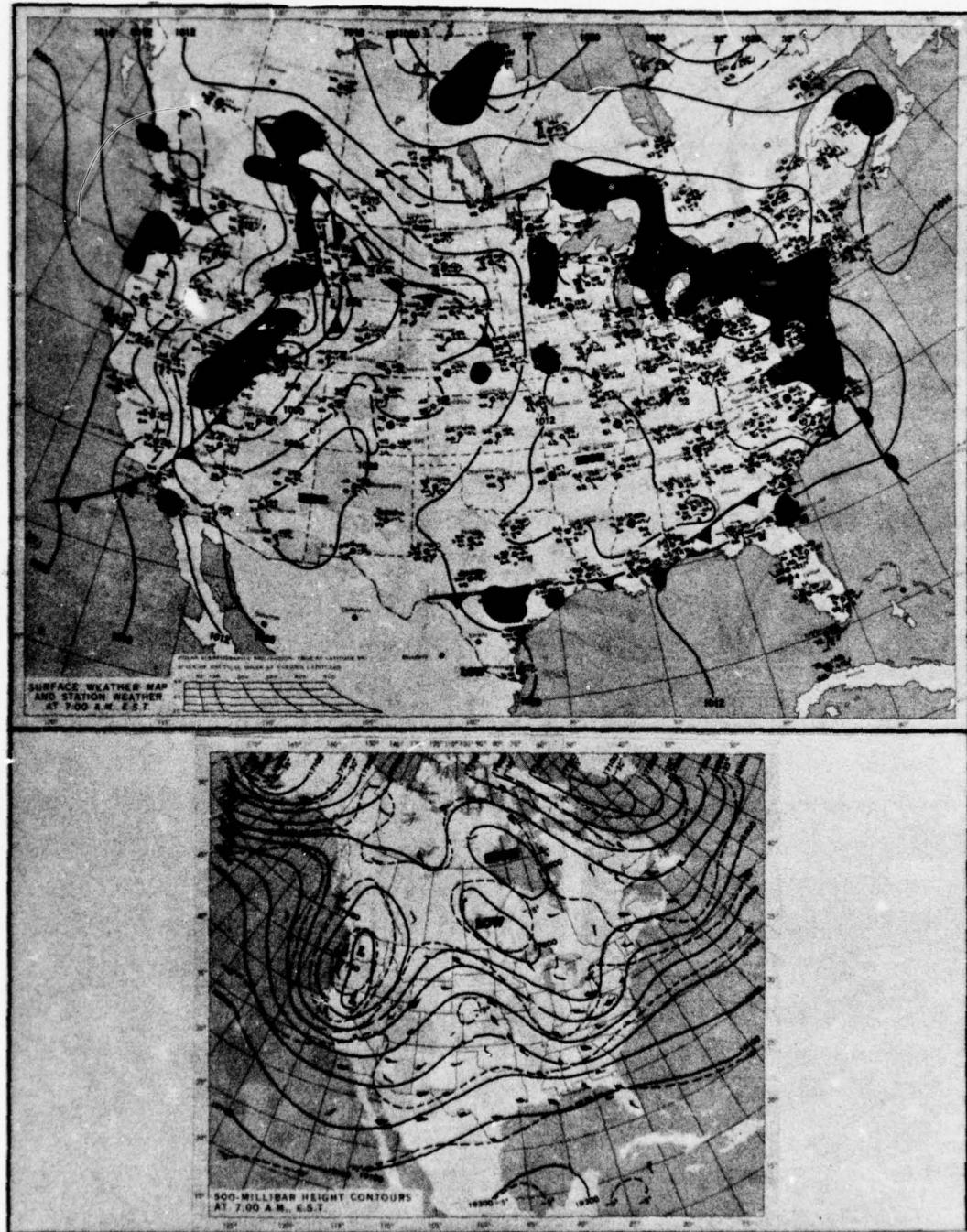


Figure 10. May 4, 1975 Surface and 500 mb Analysis for 1200Z

Nevada. The central United States was under the influence of high pressure. There was an upper level trough at 500 mb over the Great Lakes area and at the surface there were low pressure centers over Lake Erie and central Virginia. A cold front extended from the low in central Virginia and extended southwesterly along the coasts of North and South Carolina, and then westerly across central Georgia and the southern Gulf states, ending in west central Texas.

Once again since there were no DMSP satellite photographs available for May 4, 1975, a satellite photograph was obtained from the National Weather Service for that day (see Figure 11). This is an infrared picture of the western United States taken at 041815Z by the Stationary Meteorological Satellite, SMS-2.



Figure 11. May 4, 1975 SMS-2 IR Satellite Picture taken at 1815Z

CHAPTER 5

STATISTICAL ANALYSIS

5.1 Description of Statistical Method

In order to find the statistical relationship between cloud thickness and reflected solar radiance in the visible region of the spectrum (brightness), the data was fitted to a power curve of the form

$$Y = Ax^B \quad (1)$$

where Y = thickness, X = brightness, and A and B are the constants to be determined. The Least Squares Method was employed to arrive at values for A and B in Equation (1). Then a coefficient of determination R^2 , was determined for the data sample. R^2 , whose value is between 0 and 1, after being multiplied by 100, is the percent of the variance in the cloud thickness accounted for by the regression curve.

In order to test the coefficient of determination for statistical significance, a T - test was used. The T - test assumes that the population from which the sample was drawn is from a normal distribution or a near normal distribution. The T - test for the coefficient of determination is defined by

$$T = \frac{R(N-2)^{1/2}}{(1-R^2)^{1/2}} \quad (2)$$

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$$T = \frac{R(N-2)^{1/2}}{(1-R^2)^{1/2}} \quad (2)$$

where R^2 is the coefficient of determination, R is its positive square root, and N is the number of sample points. Therefore, with the assumption of normality, a null hypothesis was formed which stated: The coefficient of determination is equal to zero. A 99.5% confidence level was chosen for the T - test with $(N-2)$ degrees of freedom. Therefore, if T (defined in Equation (2)) is less than or equal to $T_{.995}$ (a statistical value obtained from a T distribution table of values), the null hypothesis would be accepted, and the conclusion that the coefficient of determination is not significantly different from zero would be accepted. Consequently, one could conclude that there was little or no correlation between the variables. If T is greater than $T_{.995}$ then the null hypothesis would be rejected and the conclusion could be drawn that the coefficient of determination was significantly different than zero.

5.2 Cloud Physics Parameter

As mentioned in the Introduction section, variations in cloud compositions may be an important factor when considering the cloud brightness values. Thus, the air mass concept is used to classify clouds in the statistical analysis. The pilot report cases, excluding those with a maritime tropical air mass origin, with their corresponding NOAA IV cloud brightness values, and the 3DNEPH cases, excluding those with a maritime tropical air mass origin, with their corresponding NOAA IV cloud brightness values, had separate regression analyses performed on them. By comparison, from a physical point of view, one could see how the different air masses would affect the coefficient of determination.

Two cloud properties whose characteristics have been measured for different air mass types are droplet concentration, and drop size distribution. As described in Fletcher (1969), studies measuring the droplet concentration of the same cloud type in different air masses have been performed. Results for cumulus clouds in maritime and continental air masses showed concentrations of 45 cm^{-3} and 228 cm^{-3} respectively. Direct comparisons for layer clouds were not available; however, figures by Squires et al. (1957) for maritime layer clouds and Diem (1948) for clouds of unknown origin do suggest that a comparison may be equally as distinct when additional data is collected. For drop size distributions Squires (1958) again has made comparisons of maritime and continental air mass clouds. Maritime cumulus clouds were found to have drop size ranges of approximately 5 to $55 \mu\text{m}$ in diameter with an average concentration of approximately 5 cm^{-3} . For continental cumulus clouds the drop size range was approximately 5 to $15 \mu\text{m}$ and had an average concentration of approximately 200 cm^{-3} . Again, with additional data, it is expected that layer clouds for the two air mass types should be as distinct. From the discussion above, one can see that clouds of maritime origin tend to have smaller droplet concentrations but have many large droplets, and continental air mass clouds tend to have large droplet concentrations of small particles. It is also clear that the droplet size and size distribution within the clouds of maritime origin are being modified constantly through the condensation-collision processes. It is the difference in the droplet size distribution which would affect the reflective properties of the cloud with respect to incident solar radiation. Therefore, the increase in the coefficient

of determination is to be expected when considering solely non-maritime air mass cases, since by excluding these cases some of the variability in the brightness variable is eliminated.

5.3 Statistical Results

For the 28 ($N = 28$) thickness and brightness values obtained from the pilot report data, the resultant power curve equation (see Figure 12) was

$$Y = 4.74X^{1.33} \quad (3)$$

The coefficient of determination was 0.66. Using Equation (2) in Section 5.1, the value of T was 7.104, and the table value of $T_{.995}$ with 26 degrees of freedom was 2.779. One can therefore say that for this data sample, the coefficient of determination, accounting for 66% of the variance between thickness and brightness, is statistically significant. Note that the correlation coefficient, R , in this case is about 82%.

There were 19 ($N = 19$) pilot report cases in non-maritime Tropical Air Masses. The power curve equation (see Figure 13) for these brightness and thickness values was

$$Y = 1.38X^{1.6} \quad (4)$$

The coefficient of determination was 0.88 ($R = 94\%$). Using Equation (2) in Section 5.1, the value of T was 11.166, and the table value of $T_{.995}$ with 17 degrees of freedom was 2.898. One can therefore say that for this data sample, the coefficient of determination, accounting for 88% of the variance between thickness and brightness, is statistically significant.

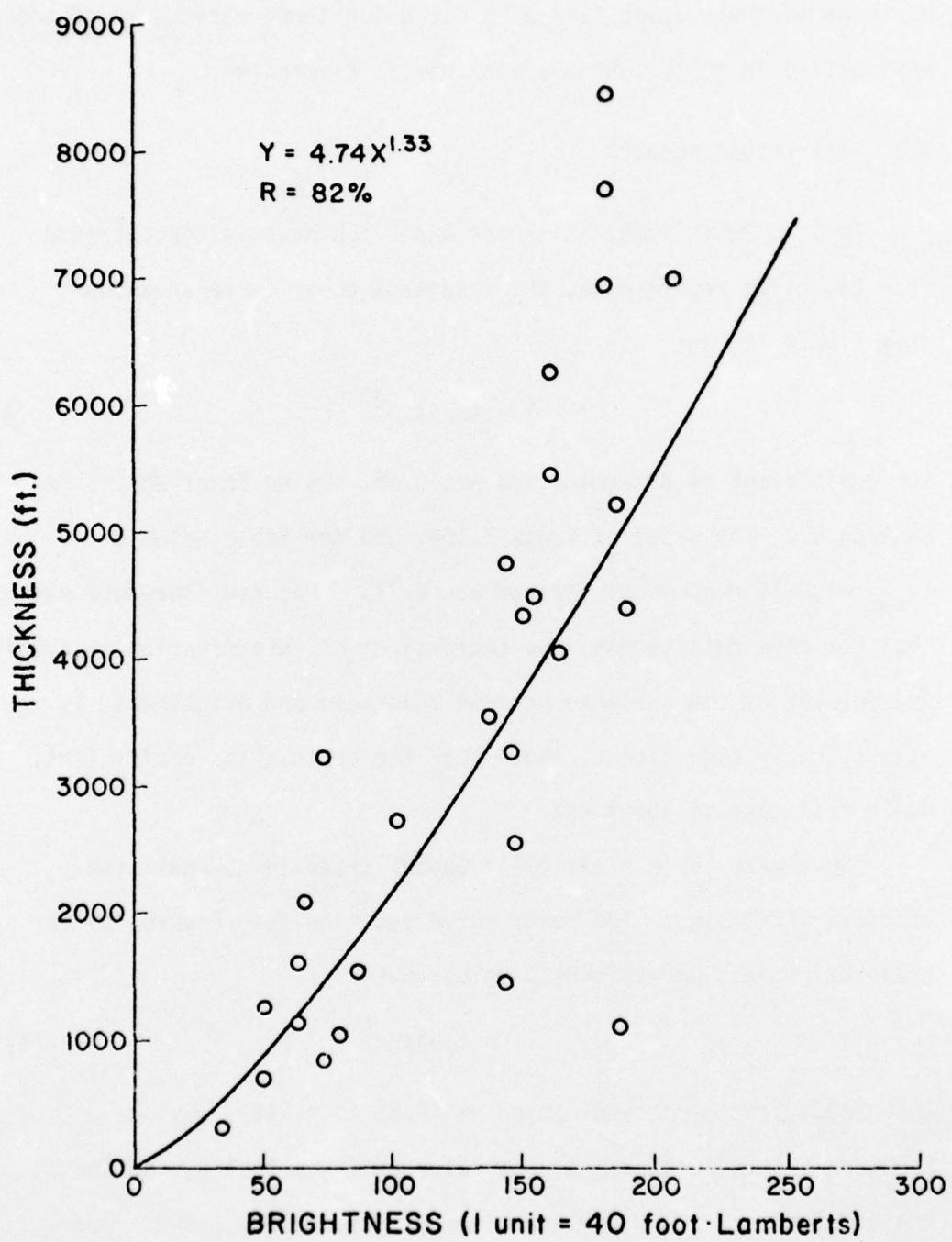


Figure 12. Regression Curve for all Pilot Report Cases

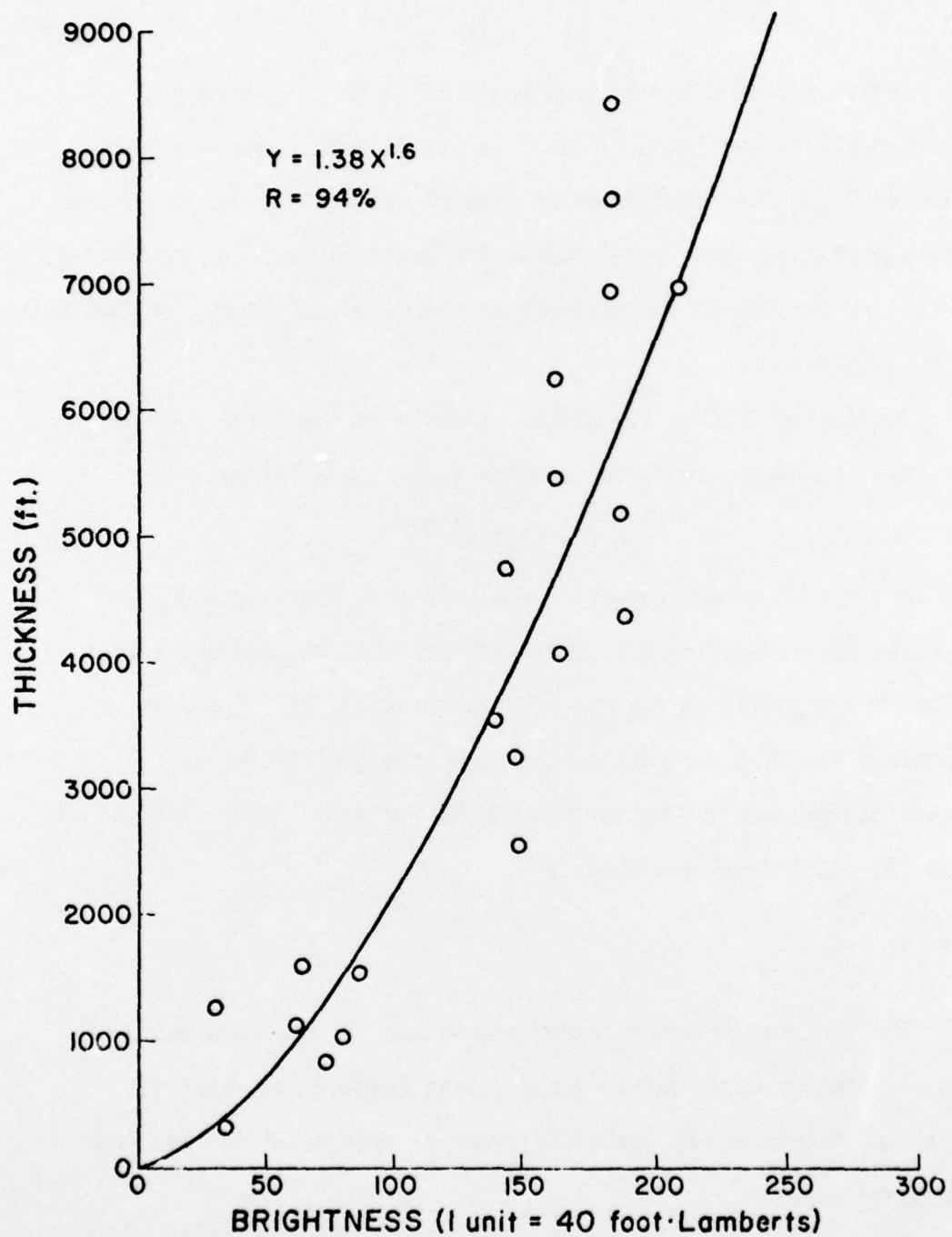


Figure 13. Regression Curve for Pilot Reports excluding Maritime Tropical Air Mass Cases.

For the 87 ($N = 87$) 3DNEPH data pairs of thickness and brightness, the resultant power curve equation (see Figure 14) was

$$Y = 7.15X^{1.26} \quad (5)$$

The coefficient of determination was 0.46 ($R = 68\%$). Using Equation (2) in Section 5.1, the T value was 8.509, and the table value of $T_{.995}$ with 85 degrees of freedom was 2.646. One can therefore say that for this data sample, the coefficient of determination, accounting for 46% of the variance in the cloud thickness, is statistically significant.

There were 35 ($N = 35$) 3DNEPH cases in non-maritime Tropical Air Masses. The power curve equation (see Figure 15) was

$$Y = 17.77X^{1.07} \quad (6)$$

The coefficient of determination was 0.55 ($R = 75\%$). Using Equation (2) in Section 5.1, the T value was 6.351, and the table value of $T_{.995}$ with 33 degrees of freedom was 2.737. One can therefore say that for this data sample, the coefficient of determination, accounting for 55% of the variance in the cloud thickness, is statistically significant.

5.4 Remarks

The data was fitted to other regression curves, such as, a semi-logarithmic curve and a linear curve; however, the best fit obtained, determined by the coefficient of determination, was from the power curve.

One of the reasons for the lower coefficients of determination of the 3DNEPH data, as compared to those of the pilot report data,

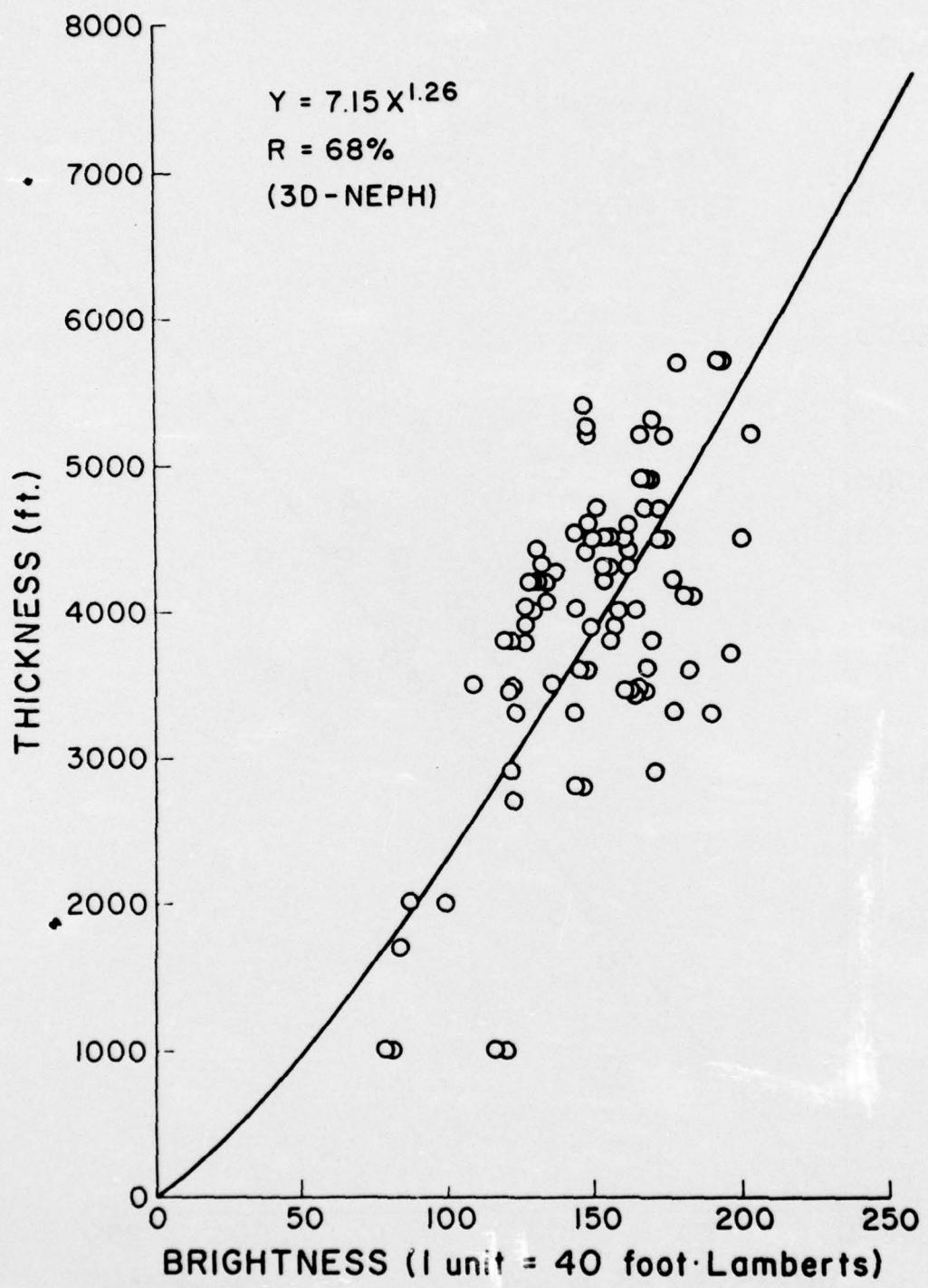


Figure 14. Regression Curve for All 3dNEPH Cases

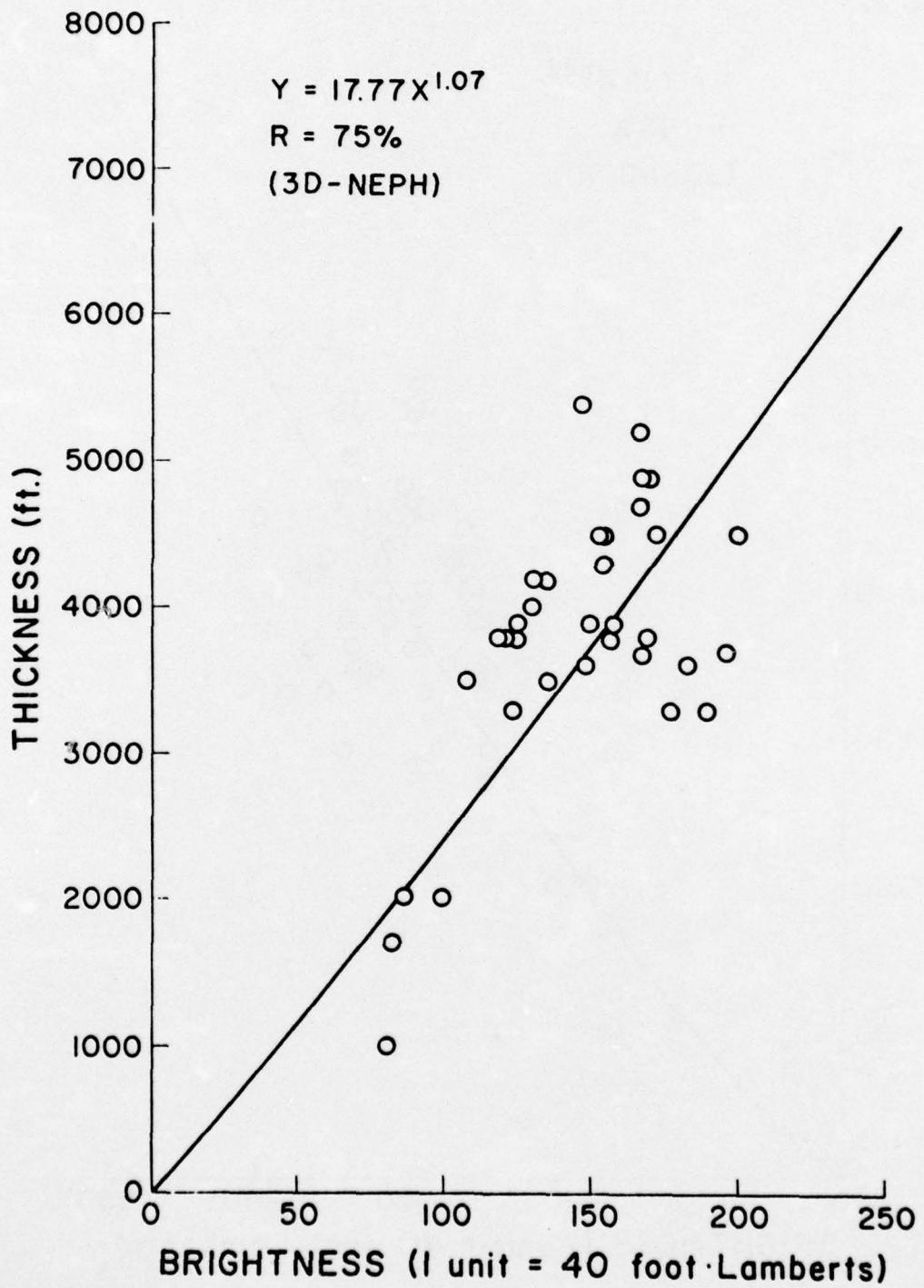


Figure 15. Regression Curve for 3dNEPH excluding Maritime Tropical Air Mass Cases

is the nature of the 3DNEPH data. As described in Chapter 4, the thicknesses of the 3DNEPH data are derived from the parameterization of aircraft reports. Thus, the resolution of the 3DNEPH thickness data is coarser than that of the pilot report thicknesses, and as a result larger errors can be introduced.

CHAPTER 6

CONCLUSIONS

A direct statistical correlation has been shown to exist between cloud thickness and the reflected solar radiation in the visible part of the spectrum (brightness). Using pilot report derived thicknesses, the regression analysis power curve accounted for more of the variance ($R^2 = 0.66$) in the observed cloud thicknesses than did a similar regression analysis power curve with 3DNEPH derived thicknesses. ($R^2 = 0.46$)

For both data samples, when a regression analysis was performed using only cases whose origin was not a maritime tropical air mass, the coefficients of determination increased. This shows that without maritime tropical air mass cases more of the variance in the observed cloud thicknesses appears to be accounted for by the regression curves.

Further study in the area of relating cloud thickness and brightness seems to be warranted. Through the use of larger sample sizes containing reliable cloud thickness reports, and further investigation of the physics involved in the interaction of the reflected sunlight and the cloud thickness and composition, a general equation which could account for more of the variance between these variables might be obtained.

Finally, perhaps the approach of the statistical analysis

reported here may also be applicable to multilayered clouds for the inference of their thicknesses.

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